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Comparative Testing of the Combined Radiant Barrier and Duct Models in the ESL's Code-Compliant Simulation Model

A Project for
Texas' Senate Bill 5 Legislation
For Reducing Pollution
In Non-Attainment and Affected Areas

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Executive Summary

This report presents a study of the application of a radiant barrier / duct model to the DOE-2.1e simulation program based on the previous methods (eQuest version 3.55 and EnergyGauge version 2.42) and the comparison of the results of the ESL's model versus the EnergyGauge program by the Florida Solar Energy Center (FSEC).

Sensitivity analyses were performed by varying duct insulation levels, supply duct area, return duct area, supply duct leakage, return duct leakage, and ceiling insulation levels. The results of sensitivity analyses show acceptable agreement versus the EnergyGauge program for duct insulation levels, supply duct area, return duct area, supply duct leakage, and ceiling insulation level. Significant differences in the return duct leakage calculations were observed. These comparisons show the ESL model is more sensitive to return duct leakage than the EnergyGauge model

Comparison of the results of the duct model for two cases (with radiant barrier and without radiant barrier) show acceptable agreements for the parameters of duct insulation, supply duct surface area, return duct surface area, supply duct leakage and ceiling insulation.

The results of savings (with and without radiant barriers) indicate that the ESL model shows slightly more savings for all parameters. In terms of the sensitivity of the results, the ESL model also shows more sensitivity for all parameters except supply duct leakage. This report used the results from the spreadsheet (Radiant_Barrier_Simulation.xls), DOE-2 input file (Default.inp) and EnergyGauge input (Habitat_radiant_barrier_test_again.enb).

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1. Introduction

In this analysis, it is assumed that a radiant barrier consists of sheets of aluminized mylar attached to the underside of rafters that support the roof deck in a residence to obstruct the radiant heat transfer between the hot roof surface and the other attic surfaces. According to the Florida Solar Energy Center (Parker et al. 2001), previous research in the Southeast has shown that roof-mounted radiant barriers can reduce the annual cooling electricity savings by 7-10%. In addition, the FSEC monitored nine homes with the radiant barrier systems and analyzed the pre- and post-cooling consumption to determine the impacts on energy use. The average cooling energy savings from a radiant barrier retrofit was 3.6 kWh/day, or about 9%. The average hourly reduction during the summer afternoon peak demand was 420 Watts (or about 16%). Radiant barriers can also provide reduced peak heating demand since the radiant barrier yields warmer attic temperatures during the night and early morning hours when the largest heating demands take place. The FSEC study showed that the attic temperature was 2°F warmer at 6 a.m. after the radiant barrier was applied in the winter time.

1.1. Methods for Approximating Radiant Barriers with the DOE-2 Program

Two methods were found in the literature to approximate radiant barriers in a DOE-2 simulation:

1) According to the eQuest program (James J. Hirsh & Associates (JJH 2004), the benefits due to radiant barriers can be calculated using information provided by the ASHRAE Handbook of Fundamentals, 1997, p. 24.13, Table 5, which assumes a 0.1 cfm/ft^2 ventilation rate (i.e., natural ventilation rate), attic temperature 80°F, sol-air temperature 120°F. In eQuest, the radiant barrier is incorporated by adding a fictitious insulation layer to the roof construction to account for the radiant barrier.

2) According to the FSEC (Parker 2005), radiant barriers were also calculated with EnergyGauge (FSEC 2005) by resetting the interior film resistance also according to the values suggested in the ASHRAE Handbook of Fundamentals. Since the start value used in EnergyGauge was not described in the publication, it was assumed that the values were the same as the value used for eQuest. Table 1 shows the DOE-2.1e simulation codes for the radiant barrier. In the case of eQuest, the fictitious material of the radiant barrier (R-value is 8.1 hr-ft^2-F/Btu) is created and added to the roof layers (RF-1 and RF-2). For the EnergyGauge method, the DOE-2.1e command for the inside film resistance (I-F-R) was changed to 8.1 hr-ft^2-F/Btu from the default value (0.68 hr-ft^2-F/Btu).

Table 1. DOE-2.1e simulation codes for fictitious radiant barriers.

eQuest

```
RB                  = MATERIAL
                    RESISTANCE       = 8.1   ..



RF-1                = LAYERS                        $NON STUD PART OF ROOF
                    MATERIAL = (SHINGLE-SIDING, PLASTIC-FILM-SEAL,
                                PLYWOOD-5/8IN, RB)  ..

RF-2                = LAYERS                        $STUD PART OF ROOF
                    MATERIAL = (SHINGLE-SIDING, PLASTIC-FILM-SEAL,
                                PLYWOOD-5/8IN, WOOD-6IN, RB) ..
```

EnergyGauge

```
RF-1                = LAYERS                        $NON STUD PART OF ROOF
                    MATERIAL = (SHINGLE-SIDING, PLASTIC-FILM-SEAL,
                                PLYWOOD-5/8IN)
                    I-F-R = 8.1   ..

RF-2                = LAYERS                        $STUD PART OF ROOF
                    MATERIAL = (SHINGLE-SIDING, PLASTIC-FILM-SEAL,
                                PLYWOOD-5/8IN, WOOD-6IN)
                    I-F-R = 8.1   ..
```

1.2. Comparison of the Radiant Barrier Calculations using Measured Data and Simulated Data from a Case-Study House

The Energy Systems Laboratory at Texas A&M University has been monitoring the environmental conditions and energy consumption from the case-study house for 5 years. The case study house is a single-story, 1,100 sq. ft. house with an attic space. The house has 3 bedrooms, 1-½ bathrooms, one living room, one dining room, one kitchen, and one utility area (Kim 2006). The materials used in the construction of the wall include vinyl siding on 7/16-inch, OSB wrapped with Tyvek with all joints taped with foil tape. The inside of the walls has ½-inch gypsum on a 2x4-inch stud construction set at 16 inches on center with blown-in, treated cellulose insulation. The ceilings are 5/8-inch, fire-coded gypsum board on 2x4-inch trusses with 12-inches of fiberglass insulation. The roof construction consists of composite shingles on 30 lb. felt on 7/16-inch OSB deck placed on 2x4-inch trusses set at 24 inches on center. The windows are double-pane, clear glass with aluminum frame without a thermal break.

Figure 1 shows the location of the sensors. The temperature and humidity sensors were installed in the supply duct, at the end of the supply duct, in the attic space, and just behind the return air grill (Kim 2006). In order to calibrate the attic temperature of the case-study house, the measured attic temperatures were used for the verification of the attic temperature simulations.

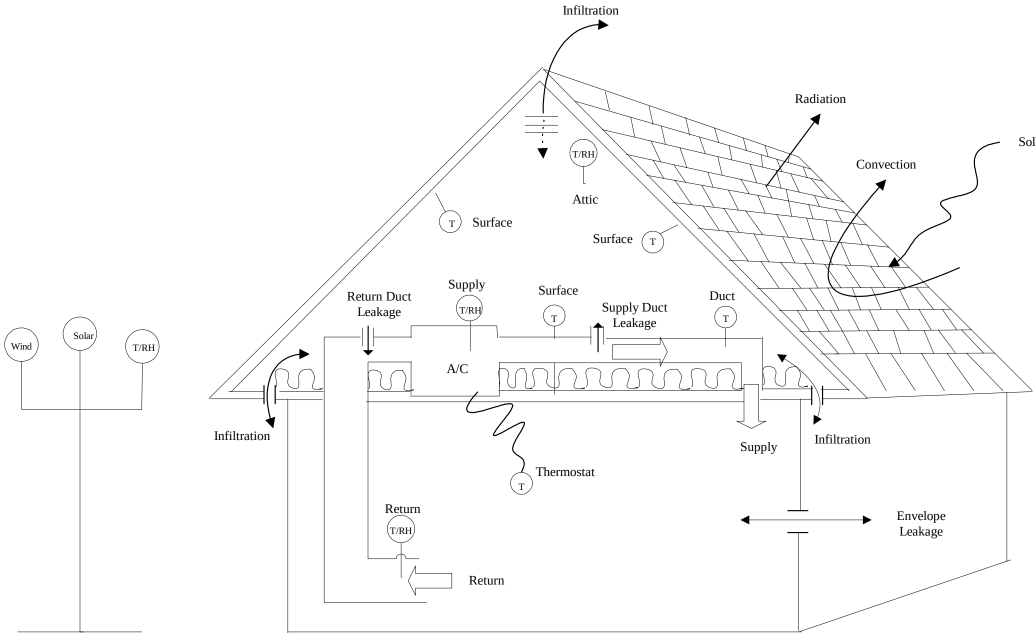

Figure 1. Diagram of sensor location.

The calibration of attic temperature was performed using the initial simulation input file of the case-study house. Figure 2 shows the measured attic temperatures and calibrated simulation temperatures of the attic in the case-study house for the period August 1 to August 14, 2004.

After the calibration procedures for the attic temperature were applied (Kim 2006), two simulation methods (eQuest and EnergyGauge) for the radiation barrier systems were applied to the simulation input file of the case-study house. Figure 3 shows the measured and simulated attic temperatures, outdoor temperatures, and attic temperatures after the two different radiant barrier calculations were applied to the case-study house simulation model. From Figure 3, the two methods showed similar attic temperature patterns when a radiant barrier was simulated. Figure 4 shows on-site solar radiation and wind speed measurements.

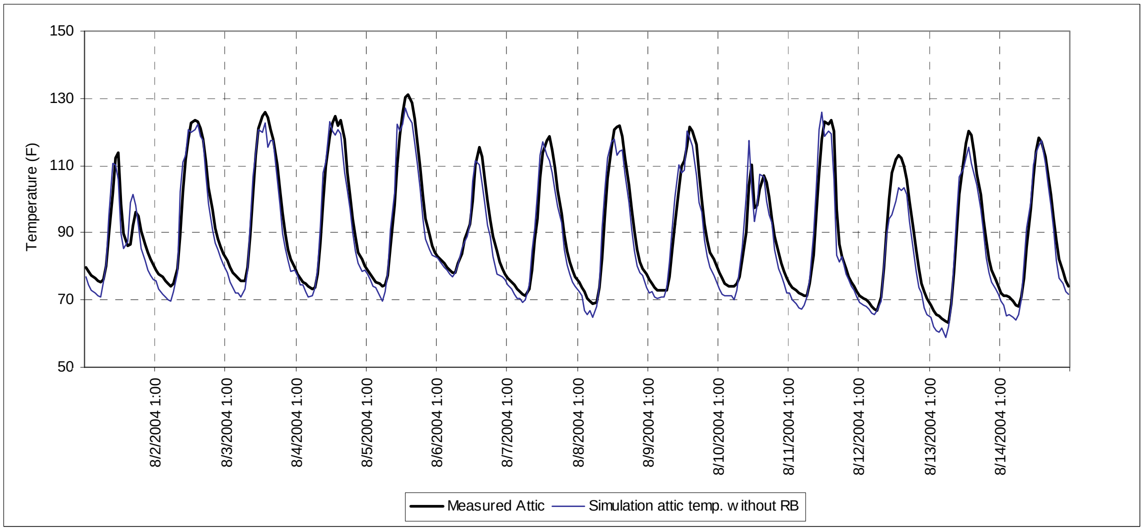

Figure 2. Temperature plot of the measured and simulated attic temperature (08/01/2004– 8/14/2006).

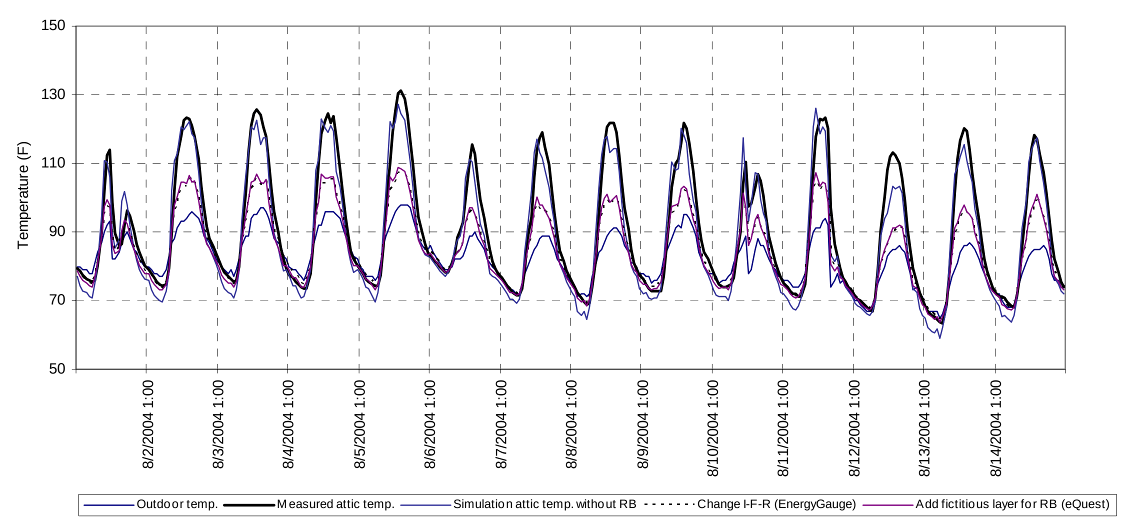

Figure 3. Temperature plot of with and without the RB for summer (08/01/2004–08/14/2006).

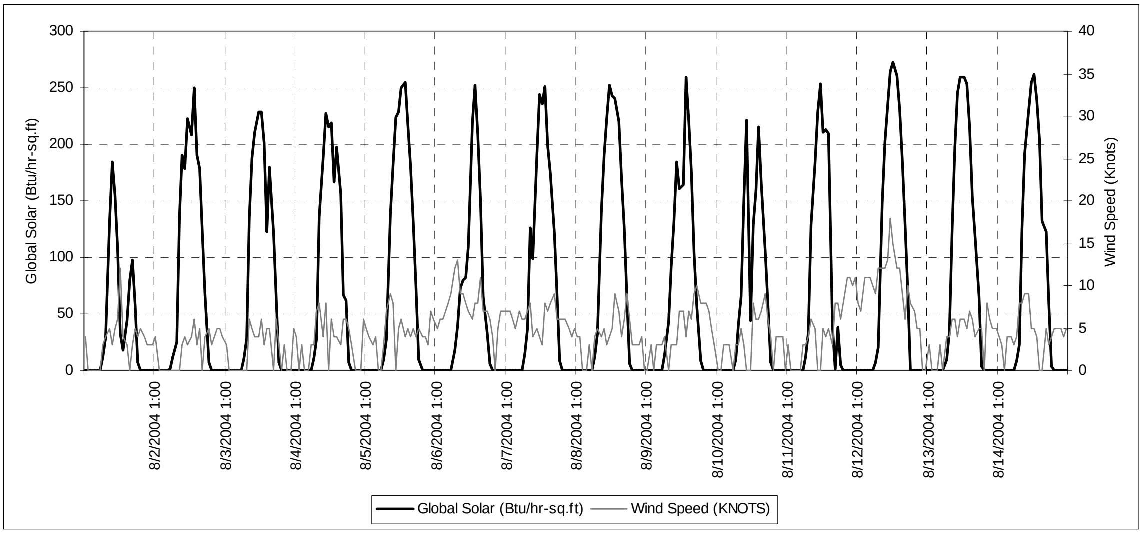

Figure 4. On-site Solar radiation and wind speed (08/01/2004–08/14/2006).

1.3. Cooling and Heating Energy Use with and without the Radiant Barrier

Figures 5 and 6 show the annual cooling and heating energy use with and without the radiant barrier. For the annual cooling energy use, there were reductions of 8.3% for the method used by EnergyGauge and 7.8% for the method used by eQuest from the base case that does not have the radiant barrier. For the annual heating energy use, there were reductions of 1.4% for both methods. These results indicate that both methods result in similar effects to the base case.

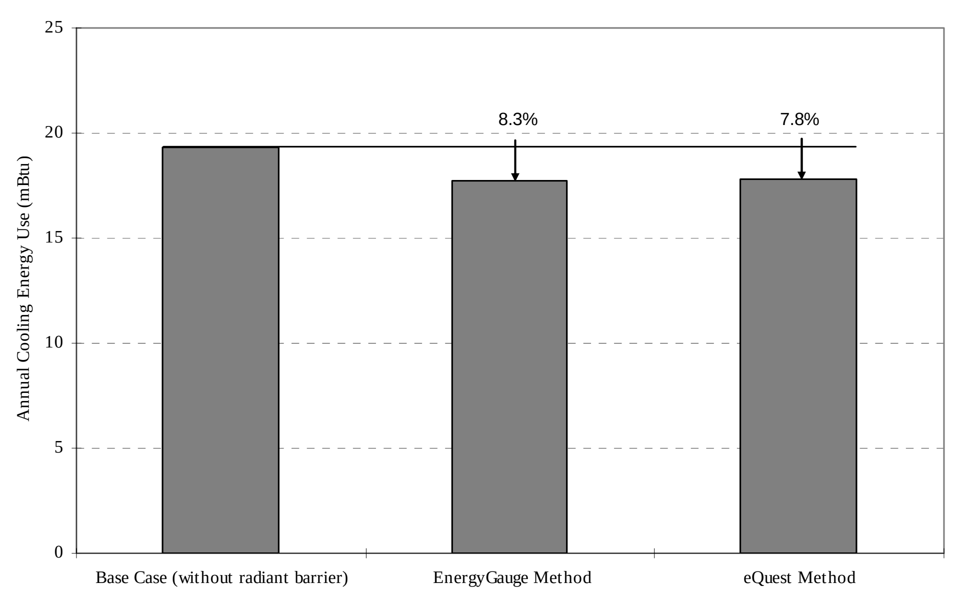

Figure 5. Cooling energy use with and without the radiant barrier.

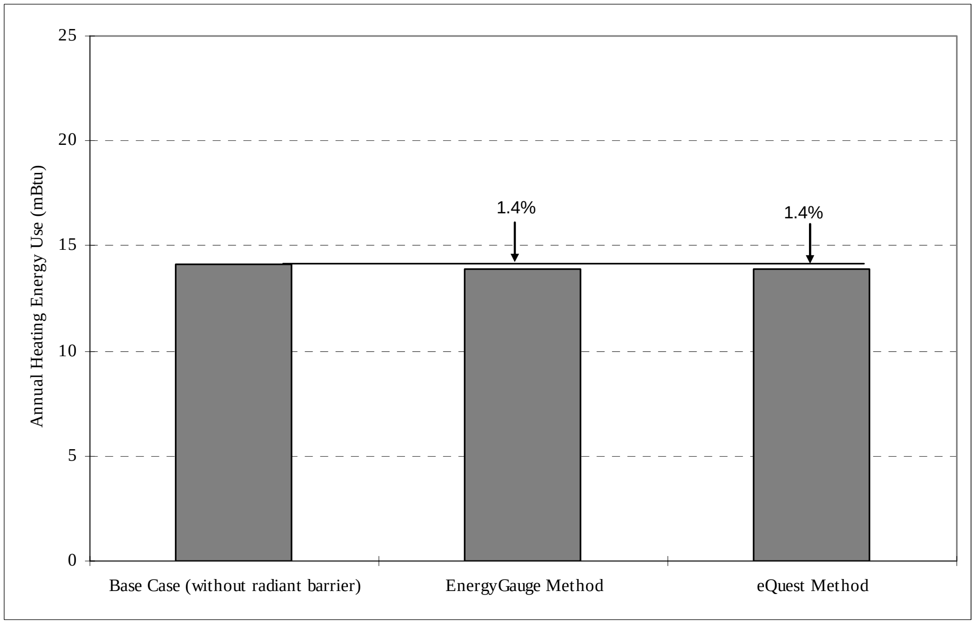

Figure 6. Heating energy use with and without the radiant barrier.

2. Comparison of the ESL's Model (Radiant Barrier with a Duct Model) versus EnergyGauge (Radiant Barrier with a Duct Model)

ASHRAE developed ASHRAE Standard 152-2004 - Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems (ASHRAE 2004) to estimate design and seasonal efficiencies for residential building systems. This calculation considers the impacts of duct leakage, location (i.e., attic space, crawl space, etc.), insulation level, climate, etc. Figure 7 shows the ESL's duct model which contains two zones, one for return side and one for the supply side, derived from the model by Palmiter and Francisco (1996), which is the basis of the Standard 152-2004 model. This model was added to the DOE-2.1e simulation program using DOE-2 FUNCTION commands.

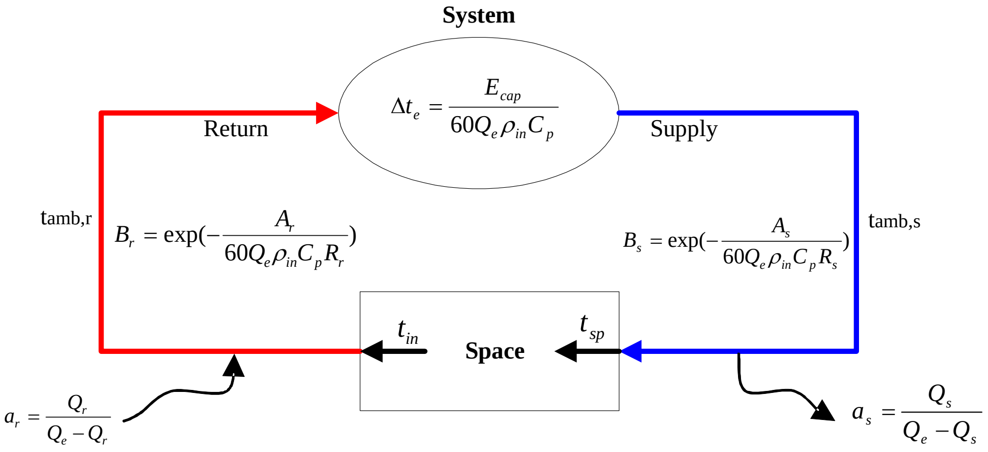

Figure 7. Schematic diagram of duct model based on ASHRAE 152-2004.

The following equations show the procedure for calculating the delivery efficiency of the heating and cooling systems that considers conduction loss and air leakage of the supply duct and return duct.

$$DE_{heating} = a_s B_s - a_s B_s (1 - B_r a_r)\frac{\Delta t_r}{\Delta t_e} - a_s (1 - B_s)\frac{\Delta t_s}{\Delta t_e} \qquad (1)$$

$$DE_{cooling} = \frac{a_s Q_e \rho_{in}}{E_{cap}}\left(\frac{E_{cap}}{60 Q_e \rho_{in}} + (1 - a_r)(h_{amb,r} - h_{in}) + a_r C_p (B_r - 1)\Delta t_r + C_p (B_s - 1)(t_{sp} - t_{amb,s})\right) \qquad (2)$$

where,

B_s = conduction efficiency of supply duct = $\exp[\frac{-A_s}{60Q_e\rho_{in}C_pR_s}]$

B_r = conduction efficiency of return duct = $\exp[\frac{-A_r}{60Q_e\rho_{in}C_pR_r}]$

a_s = air leakage efficiency of the duct of supply duct = $(\frac{Q_e - Q_s}{Q_e})$

a_r = air leakage efficiency of the duct of return duct = $(\frac{Q_e - Q_r}{Q_e})$

E_{cap} = capacity of the equipment (Btu/hr),

Q_e = system air flow (CFM),

C_p = specific heat (Btu/(lb$_m$·°F)),

Δt_e = temperature rise across the equipment (°F) = $\dfrac{E_{cap}}{60 Q_e \rho_{in} C_p}$

Δt_s = temperature difference between the building and the ambient temperature surrounding the supply (°F) $= t_{in} - t_{amb,s}$

Δt_r = temperature difference between the building and the ambient temperature surrounding the return (°F) $= t_{in} - t_{amb,r}$,

t_{in} = temperature of indoor air (°F),

t_{sp} = supply plenum air temperature (°F),

$t_{amb,s}$ = ambient temperature for supply ducts (°F),

$t_{amb,r}$ = ambient temperature for return ducts (°F),

$h_{amb,r}$ = enthalpy of ambient air for return (Btu/hr),

h_{in} = enthalpy of air inside conditioned space (Btu/hr),

A_s = supply duct area (ft^2),

A_r = return duct area (ft^2),

ρ_{in} = density of air (lb/ft^3),

R_s = thermal resistance of supply duct (hr-ft^2-°F /Btu),

R_r = thermal resistance of return duct (hr-ft^2-°F /Btu).

To accomplish this, three function commands (SAVETEMP, DUCT, and DUCT2) were used: 1) The SAVETEMP function saves the buffer zone temperature and conditioned space temperature to send these temperatures to the next function; 2) The DUCT function calculates the delivery efficiency using temperature data from the hourly report and user inputs. Then, it modifies the Energy Input Ratio (EIR) every hour in proportion to the losses. The concept for this EIR modification came from Huang (2001); and 3) the DUCT2 function then changes the modified EIR back to the original value for the next calculation.

In order to verify the duct model based on ASHRAE 152-2004, the model was compared with EnergyGuage version 2.42 from the Florida Solar Energy Center, which can consider the duct heat gain from an attic space. To perform the comparison, a house with a similar size to the case-study house was developed with EnergyGuage version 2.42, and then several parameters were varied to compare with results from each simulation. Houston TMY2 data were used for all simulations. A sensitivity analysis was then performed by changing parameters including the supply duct area (ft^2), return duct area (ft^2), supply duct R-value, return duct R-value, supply duct leakage rate (%), return duct leakage (%), and ceiling insulation.

3. Comparisons of Duct Model with and without Radiant Barrier

3.1 Comparison of Duct Model with Radiant Barrier

Figures 8 to 13 show the annual cooling energy use (kWh) and percentage difference (%) using the ESL model versus the FSEC's program, EnergyGauge, both with radiant barrier models. Each model is compared against a base case as shown.

Figure 8 shows the results of varying the duct insulation (supply and return) from R-6 (base case) to R-4, which resulted in an annual cooling energy increase of 3.8% for the ESL model and .8% for EnergyGauge. Increasing the duct insulation level from R-6 (base case) to R-12 showed an annual cooling energy reduction of 1.8% for R-8, 2.9% for R-10, and 3.6% for R-12 from the ESL model; and 1.0% for R-8, 1.7% for R-10, and 2.1% for R-12 for EnergyGauge. These results are in reasonable agreement although the ESL model appears to be more sensitive to insulation changes than the FSEC model.

When compared to the base case where the supply duct surface area is 30% of the conditioned space area (330 ft^2), the simulation results for different supply duct areas (Figure 9) show a 2.3% reduction for a 20% supply duct area (220 ft^2), a 1.1% reduction for a 25% supply duct area (275 ft^2), a 1.2% increase for a 35% supply duct area (385ft^2), and a 2.3% increase for a 40% supply duct area (440 ft^2) using the ESL model. EnergyGauge shows similar results with a 1.4% reduction for a 20% supply duct area, a 0.7% reduction for a 25% supply duct area, a 0.7% increase supply for a 35% duct area, and a 1.4% increase for a 40% supply duct area from the base case.

When compared to the base case where the return duct surface area is 6% of the conditioned space area (55 ft^2) (Figure 10), the results show a 0.3% reduction for a 2% return duct area (22 ft^2), a 0.1% reduction for a 4% return duct area (44 ft^2), a 0.3% increase for an 8% return duct area (88 ft^2), and a 0.5% increase for a 10% return duct area (110 ft^2) using the ESL model. When using EnergyGauge, the results show a 0.2% reduction for a 2% return duct area, a 0.1% reduction for a 4% return duct area, a 0.2% increase for an 8% return duct area, and a 0.4% increase for a 10% return duct area.

For different supply duct leakages (Figure 11), the ESL model showed a 5.3% reduction for a 5% supply duct leakage, a 5.9% increase for a 15% supply duct leakage, and a 12.5% increase for a 20% supply duct leakage, as compared to the base case, which is a 10% supply duct leakage. EnergyGauge shows a 6.6% reduction for a 5% supply duct leakage, a 7.6% increase for a 15% supply duct leakage, and a 16.2% increase for a 20% supply duct leakage.

The return duct leakage variations were also performed (Figure 12). When a different return duct leakage rate was applied to the base case (a 10% return duct leakage rate), there was a 9.7% decrease for a 5% return duct leakage rate, a 12.6% increase for a 15% return duct leakage rate, and a 30.1% increase for a 20% return duct leakage rate from the ESL model. For EnergyGauge, there was a 3.1% decrease for a 5% return duct leakage, a 3.0% increase for a 15% return duct leakage, and a 6.0% increase for a 20% return duct leakage from the base case (a 10% return duct leakage rate). The return duct leakage variations showed significant differences between the ESL model and EnergyGauge.

When the ceiling insulation level was changed from the base case (R-19) in the simulations (Figure 13), the ESL model showed a 2.8% increase for R-10 ceiling insulation, a 0.9% increase for R-15 ceiling insulation, a 0.9% reduction for R-25 ceiling insulation, and a 1.4% reduction for R-30 ceiling insulation. EnergyGauge shows a 3.1% increase for R-10 ceiling insulation, a 1.1% increase for R-15 ceiling insulation, a 1.3% reduction for R-25 ceiling insulation, and a 2.1% increase for R-30 ceiling insulation.

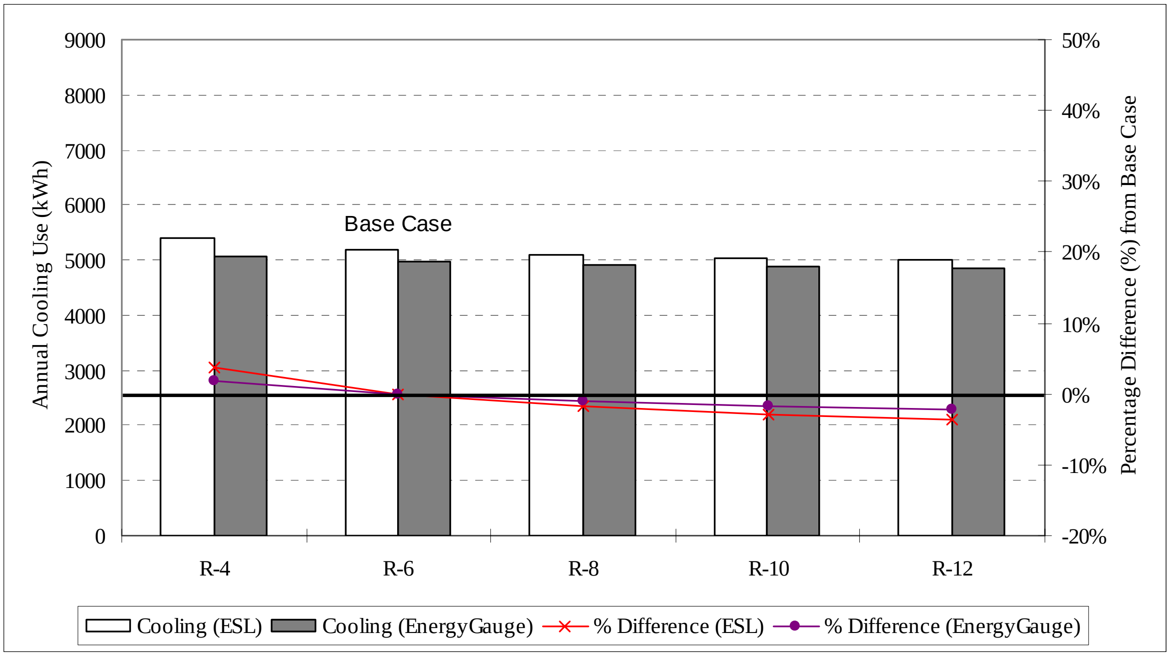

Figure 8. Duct insulation.

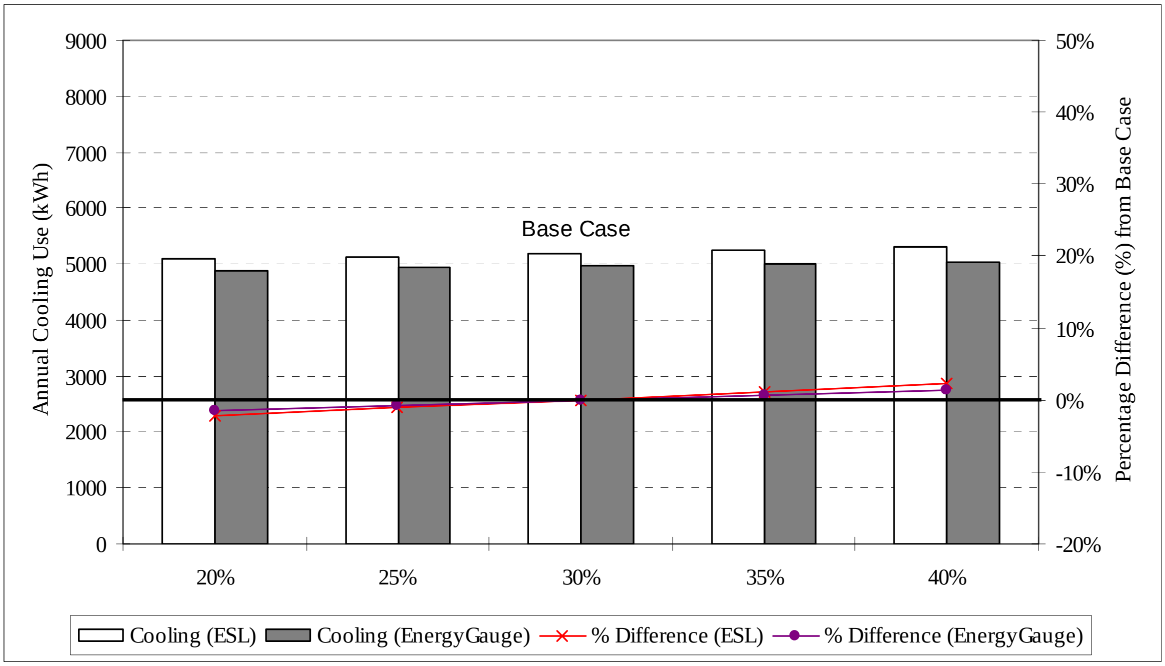

Figure 9. Supply duct area (% of conditioned space).

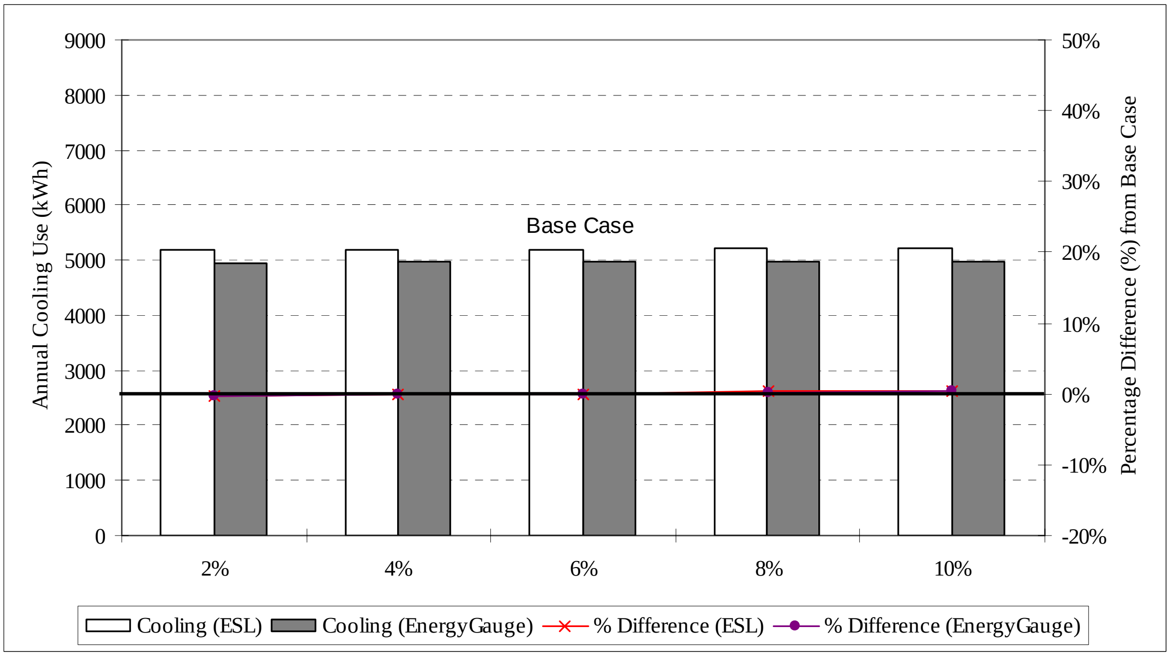

Figure 10. Return duct area (% of conditioned space).

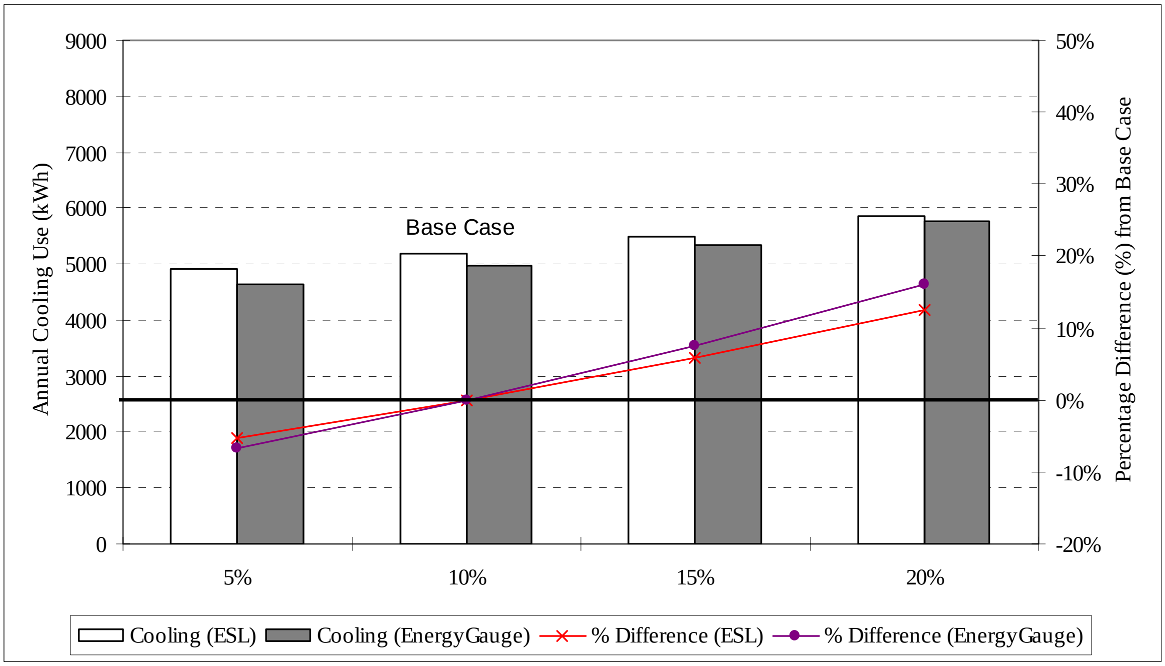

Figure 11. Supply duct leakage (% of conditioned space).

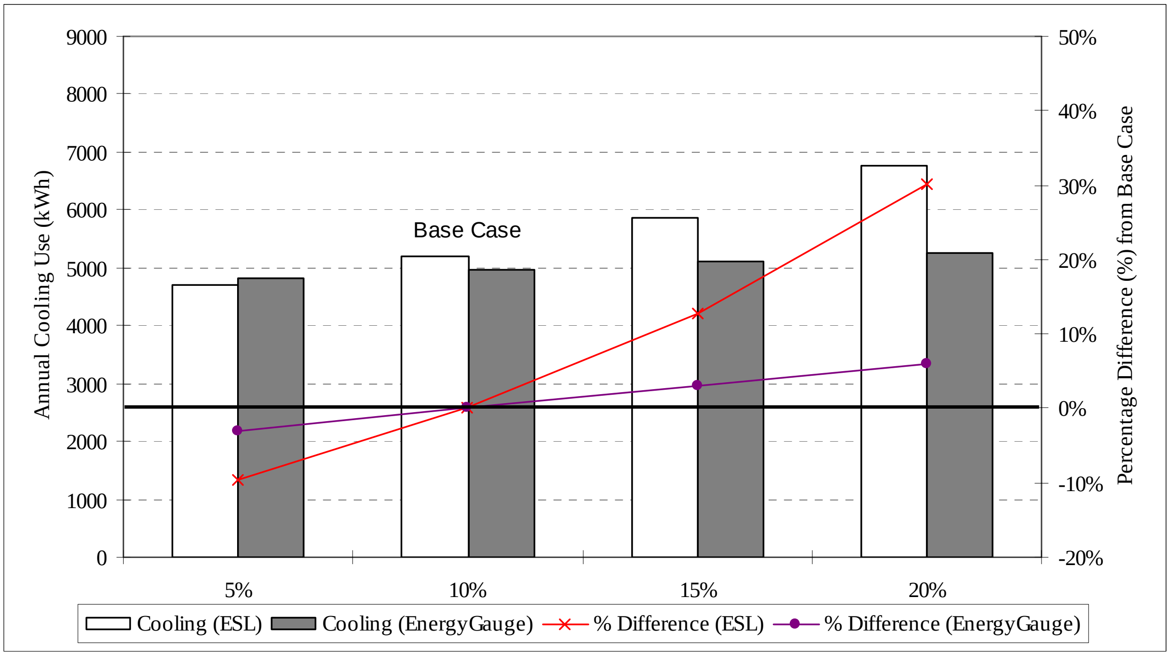

Figure 12. Return duct leakage (% of conditioned space).

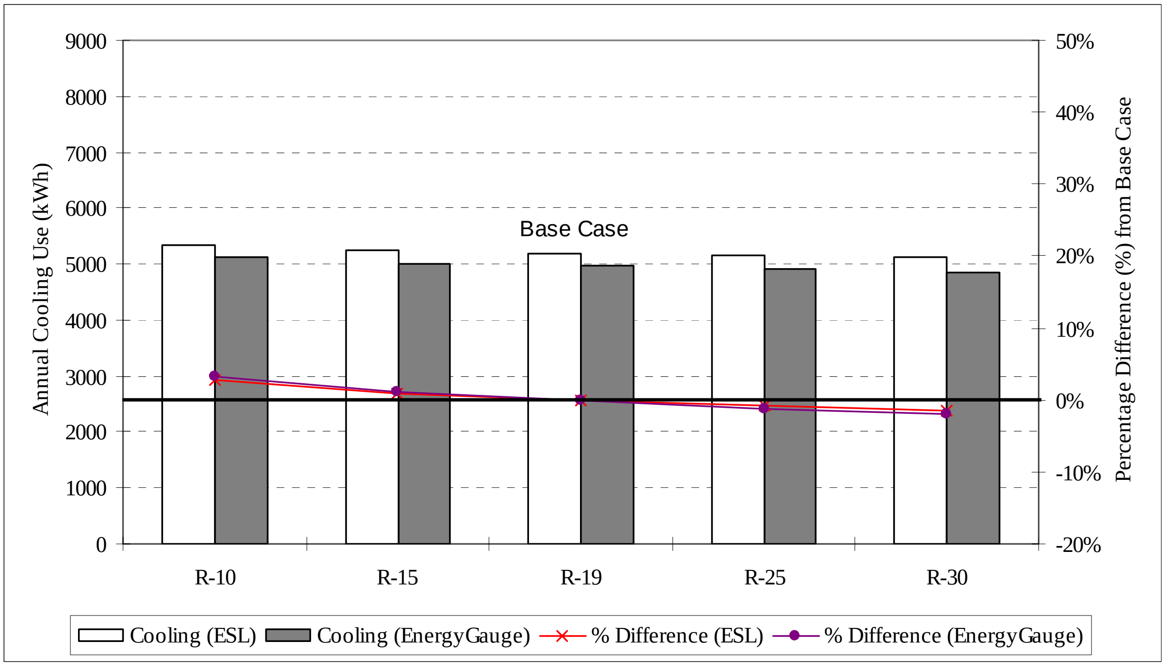

Figure 13. Ceiling insulation.

3.2. Comparison of Duct Model without Radiant Barrier

Figures 14 to 19 show the annual cooling energy use (kWh) and percentage difference (%) using the ESL model versus EnergyGauge, both without radiant barriers.

When compared to the base case where the duct insulation level (supply and return) was R-6 (Figure 14), the results showed a 5.5% increase for an R-4 duct insulation level, a 2.5% reduction for an R-8 duct insulation level, a 4.0% reduction for an R-10 duct insulation level, and a 4.9% reduction for an R-12 duct insulation level using the ESL model. When using EnergyGauge, the results showed a 2.0% increase for an R-4 duct insulation level, a 1.1% reduction for an R-8 duct insulation level, a 1.8 % increase for an R-10 duct insulation level, and a 2.3% increase for an R-12 duct insulation level.

When the supply duct surface area was changed from the base case, which is 30% of conditioned space (330 ft^2) in the simulations (Figure 15), the ESL model showed a 3.1% decrease for a 20% supply duct area (220 ft^2), a 1.6% decrease for a 25% supply duct area (275 ft^2), a 1.6% increase for a 35% supply duct area (385 ft^2), and a 3.3% increase for a 40% supply duct area (440 ft^2). EnergyGauge shows a 1.5% decrease for a 20% supply duct area, a 0.7% decrease for a 25% supply duct area, a 0.8% increase for a 35% supply duct area, and a 1.5% increase for a 40% supply duct area.

The comparisons of variations in the return duct surface area (Figure 16) compared the return duct surface area from the base case, where the return duct surface area is 6% of conditioned space area (55 ft^2), reveal that the annual cooling energy shows a 0.5% reduction for a 2% return duct area (22 ft^2), a 0.2% reduction for a 4% return duct area (44 ft^2), a 0.5% increase for an 8% return duct area (88 ft^2), and a 0.9% increase for a 10% return duct area (110 ft^2) from the ESL model. EnergyGauge shows reductions of a 0.2% for a 2% return duct area and a 0.1% for a 4% return duct area, and increases of a 0.3% for an 8% return duct area and a 0.4% for a 10% return duct area.

The comparisons of the supply duct leakages (Figure 17) show a 5.3% reduction for a 5% supply duct leakage, a 5.9% increase for a 15% supply duct leakage, and a 12.5% increase for a 20% supply duct leakage from the base case (10% supply duct leakage) using the ESL model. EnergyGauge shows a 6.5% reduction for a 5% supply duct leakage, a 7.5% increase for a 15% supply duct leakage, and a 15.9% increase for a 20% supply duct leakage from the base case.

For different return duct leakages (Figure 18), the ESL model shows a 11.8% reduction for a 5% return duct leakage, a 16.9% increase for a 15% return duct leakage, and a 44.2% increase for a 20% return duct leakage, as compared to the base case which is a 10% return duct leakage. EnergyGauge shows a 3.8% reduction for a 5% return duct leakage, a 3.6% increase for a 15% return duct leakage, a 7.0% increase for a 20% return duct leakage. The simulations of return duct leakage variations also show significant differences between the ESL model and EnergyGauge for the simulation results with radiant barriers (Figure 12).

When a different ceiling insulation level (Figure 19) is applied to the base case (R-19 ceiling insulation), there was a 4.5% increase for R-10 ceiling insulation, a 1.5% increase for R-15 ceiling insulation, a 1.4% decrease for R-25 ceiling insulation, and a 2.2% decrease for R-30 ceiling insulation from the ESL model. For EnergyGauge, there was a 4.5% increase for R-10 ceiling insulation, a 1.5% increase for R-15 ceiling insulation, a 1.8% decrease for R-25 ceiling insulation, and a 2.9% decrease for R-30 ceiling insulation from the base case.

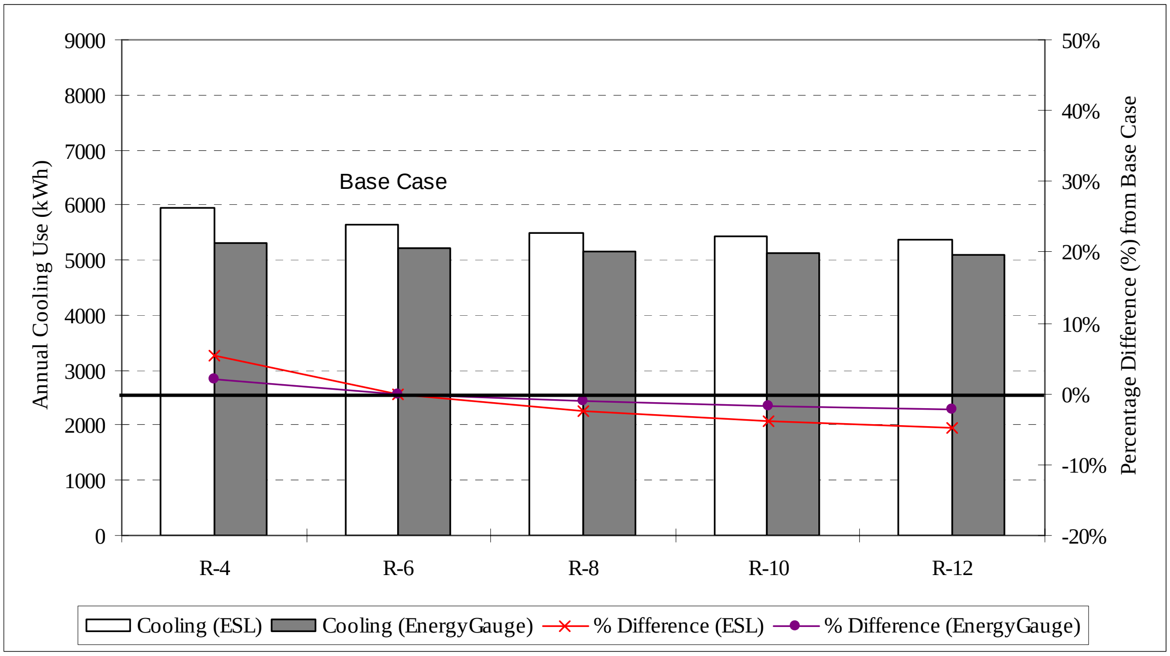

Figure 14. Duct insulation.

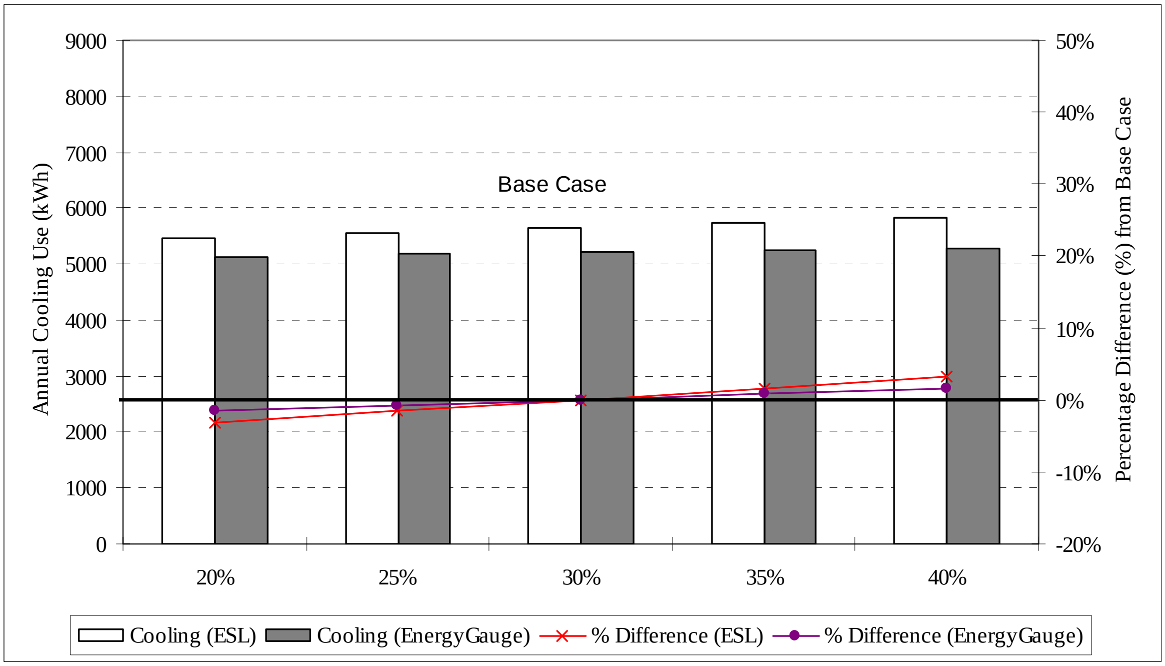

Figure 15. Supply duct area (% of conditioned space).

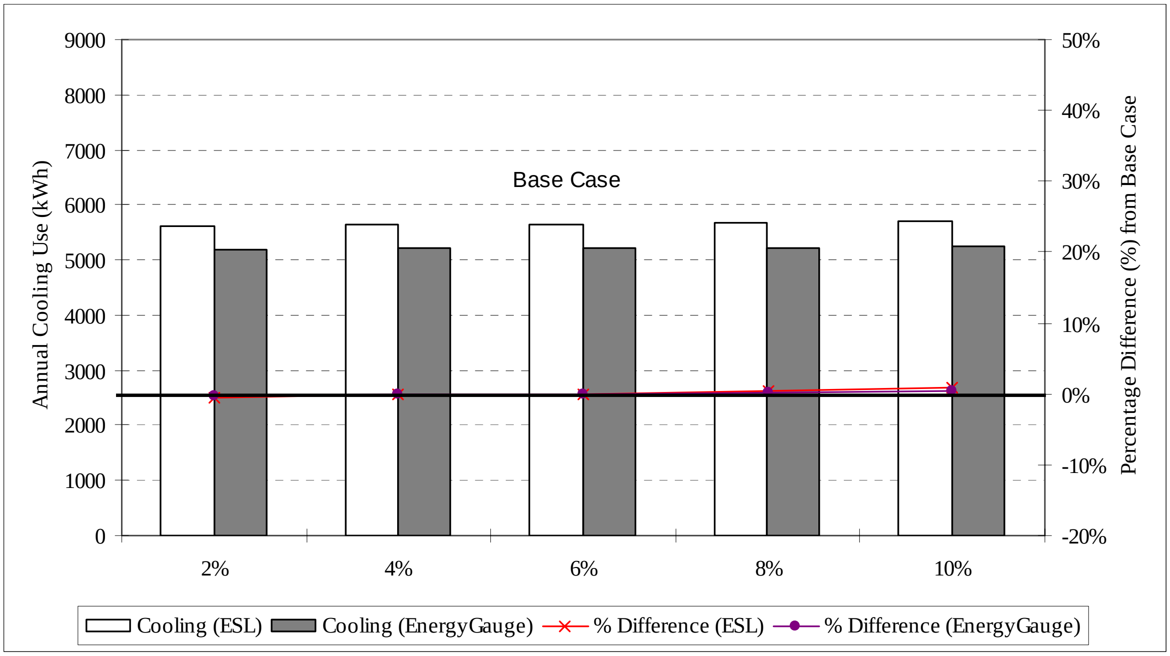

Figure 16. Return duct area (% of conditioned space).

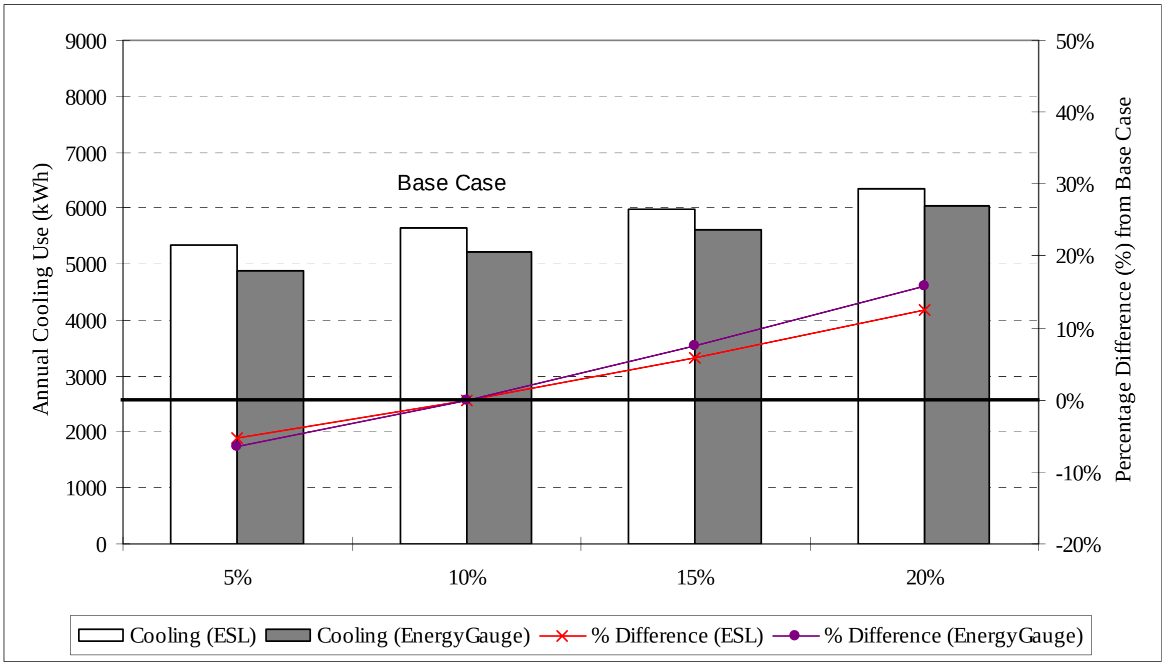

Figure 17. Supply duct leakage (% of conditioned space).

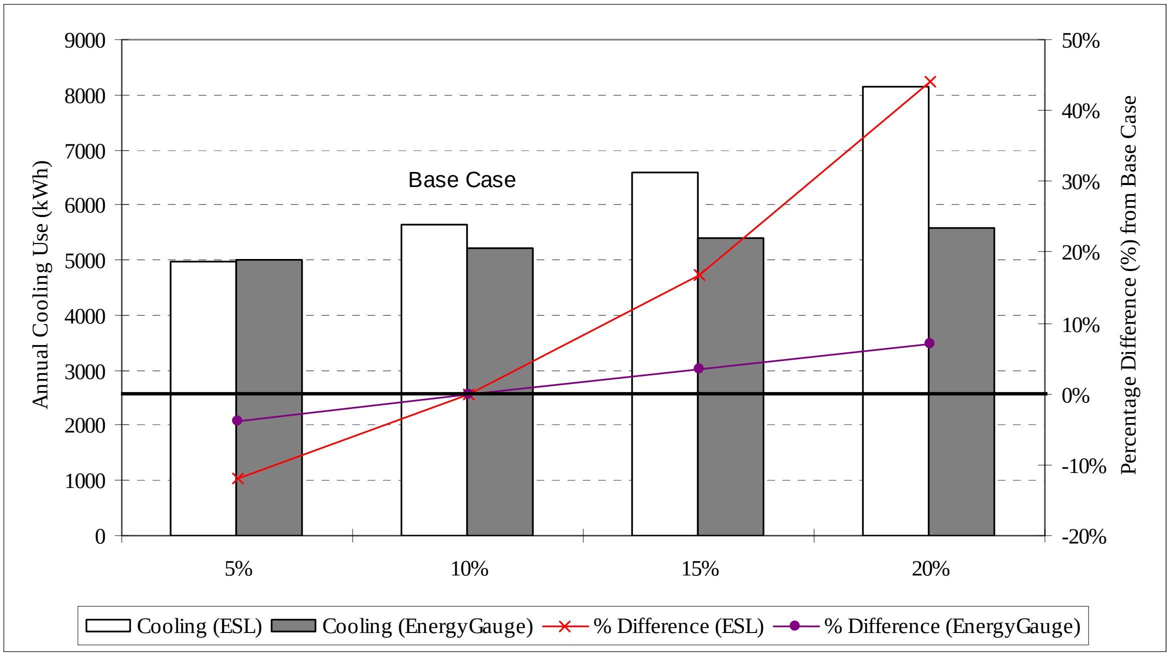

Figure 18. Return duct leakage (% of conditioned space).

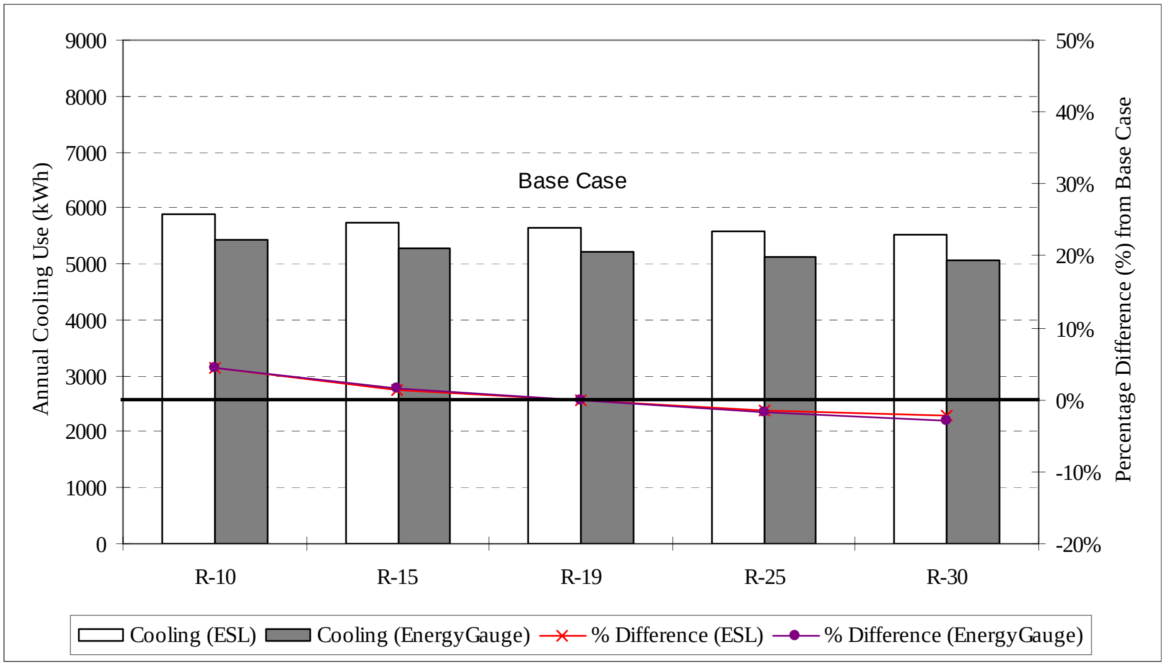

Figure 19. Ceiling insulation.

4. Comparisons of Saving Differences from Radiant Barrier of the ESL Model and EnergyGauge

Figures 20 to 37 show the percentage of savings with and without the radiant barrier using the ESL model and EnergyGauge program for various configurations.

In the case of the duct insulation (Figures 20 to 22), the results of the ESL simulation model show a 9.4% saving for R-4 duct insulation, an 8.0% saving for R-6 duct insulation, a 7.3% saving for R-8 duct insulation, a 6.9% saving for R-10 duct insulation, and a 6.7% saving for R-12 insulation after the radiant barrier is applied to the simulation model, while the results from EnergyGauge show a 4.9% saving for R-4, a 4.8% saving for R-6, a 4.7% saving for R-8, a 4.6% saving for R-10 and R-12 duct insulation level after the radiant barrier is applied.

The results of different supply duct surface area show a 7.2% saving for a 20% supply duct area (220 ft^2), a 7.6% saving for a 25% supply duct area (275 ft^2), an 8.0% saving for a 30% supply duct area (330 ft^2), a 8.4% saving for a 35% supply duct area (385 ft^2), and an 8.8% saving for a 40% supply duct area (440 ft^2) after radiant barrier is applied to the ESL model. EnergyGauge shows a 4.7% saving for 20% and 25% supply duct areas, a 4.8% saving for 30% and 35% supply duct areas, and a 4.9% saving for a 40% supply duct areas (Figures 23 to 25).

When increasing the return duct surface area (Figures 26 to 28), the ESL model shows a 7.8% saving for a 2% return duct surface area (22 ft^2), a 7.9% saving for a 4% return duct surface area (44 ft^2), an 8.0% saving for a 6% return duct surface area (55 ft^2), an 8.2% saving for an 8% return duct surface area (88 ft^2), and a 8.3% saving for a 10% return duct surface area (110 ft^2). EnergyGauge shows a 4.7% saving for a 2% return duct area and a 4.8% saving for 4%, 6%, 8% and 10% return duct surface area.

Using different supply duct leakages (Figures 29 to 31), the ESL model shows an 8.0% saving for all supply duct leakages, and EnergyGauge shows a 0.7% saving for a 5% supply duct leakage, a 1.4% saving for 10% and 15% supply duct leakage, and a 0.7% saving for a 10% supply duct leakage.

Increasing return duct leakage (Figures 32 to 34) with radiant barriers produces a 5.7% saving for a 5% return duct leakage, a 8.0% saving for a 10% return duct leakage, a 11.3% saving for a 15% return duct leakage, and a 17.0% saving for a 20% return duct leakage from the ESL model. EnergyGauge shows a 0.7% saving for a 5% return duct leakage, a 1.4% saving for 10% and 15% return duct leakage, and a 2.0% saving for a 20% return duct leakage.

In the case of different ceiling insulation levels (Figures 35 to 37), the ESL shows a 9.4% saving for R-10 ceiling insulation, an 8.4% saving for R-15 ceiling insulation, a 8.0% saving for R-19 ceiling insulation, a 7.5% saving for R-25 ceiling insulation, and a 7.2% saving for R-30 ceiling insulation. EnergyGauge shows a 6.0% saving for R-10 ceiling insulation, a 5.2% saving for R-15 ceiling insulation, a 4.8% saving for R-19 ceiling insulation, a 4.2% saving for R-25 ceiling insulation, and a 3.9% saving for R-30 ceiling insulation.

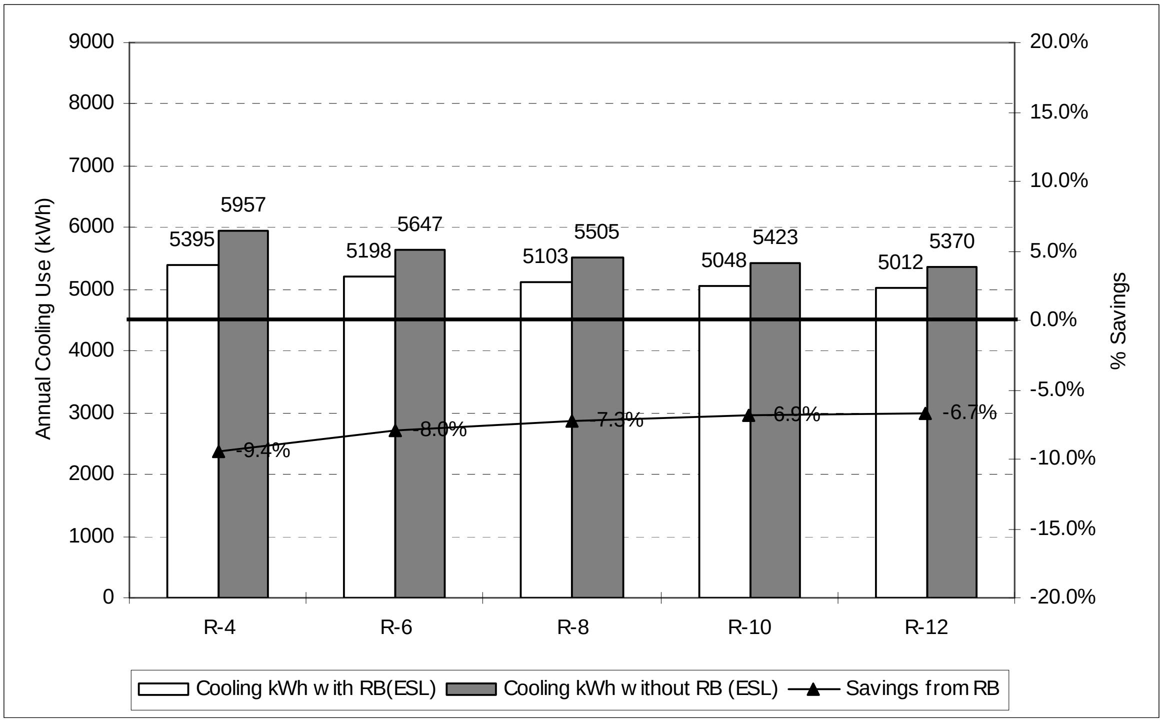

Figure 20. Cooling energy differences and % savings from varying duct insulation with radiant barrier and without radiant barrier - ESL model.

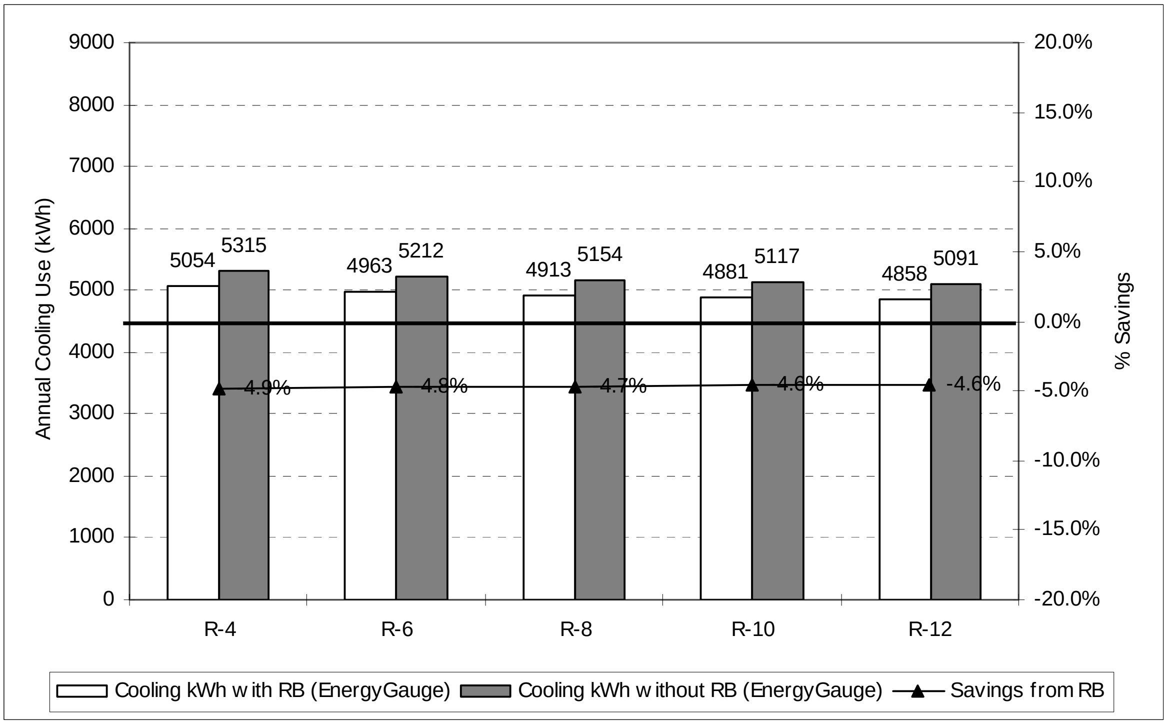

Figure 21. Cooling energy differences and % savings from varying duct insulation with radiant barrier and without radiant barrier – EnergyGauge.

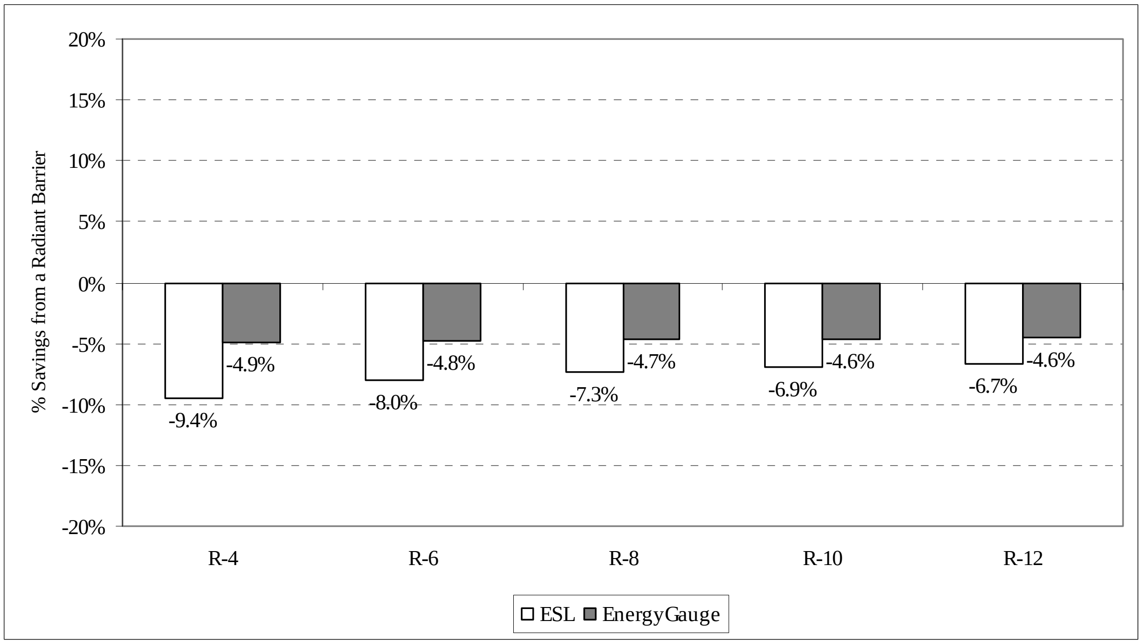

Figure 22. Comparison of cooling savings from varying duct insulation with radiant barrier and without radiant barrier for the ESL model and EnergyGauge.

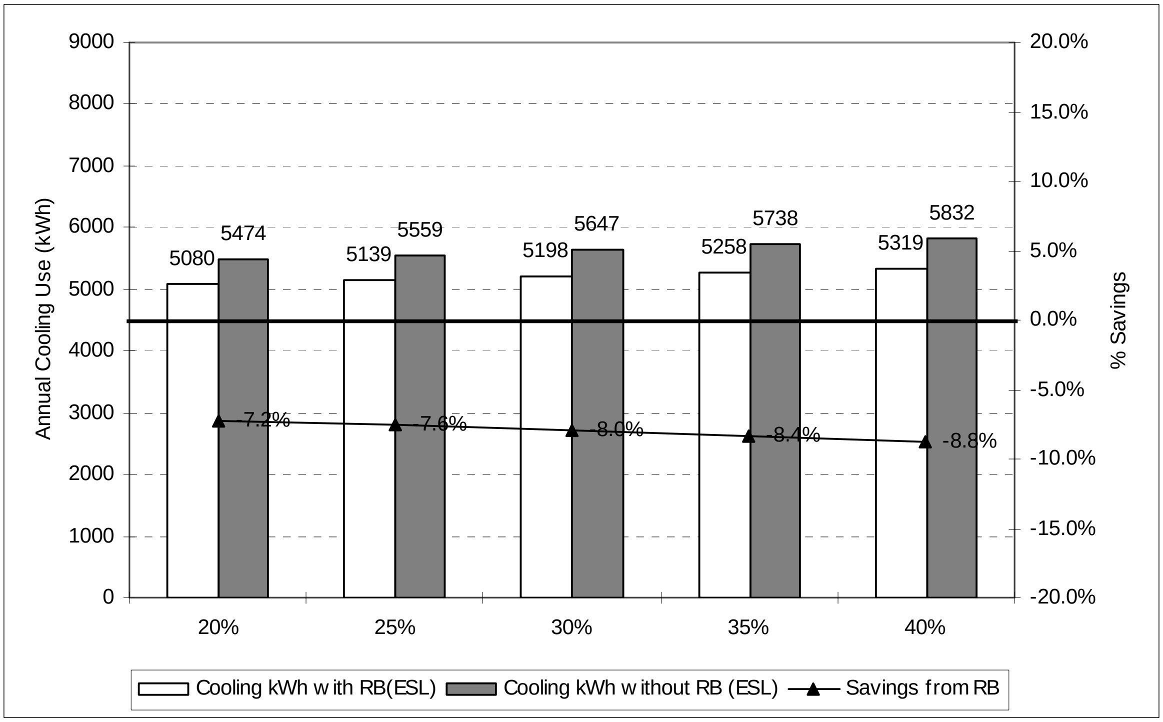

Figure 23. Cooling energy differences and % savings from varying supply duct area (% of conditioned space) with radiant barrier and without radiant barrier - ESL model.

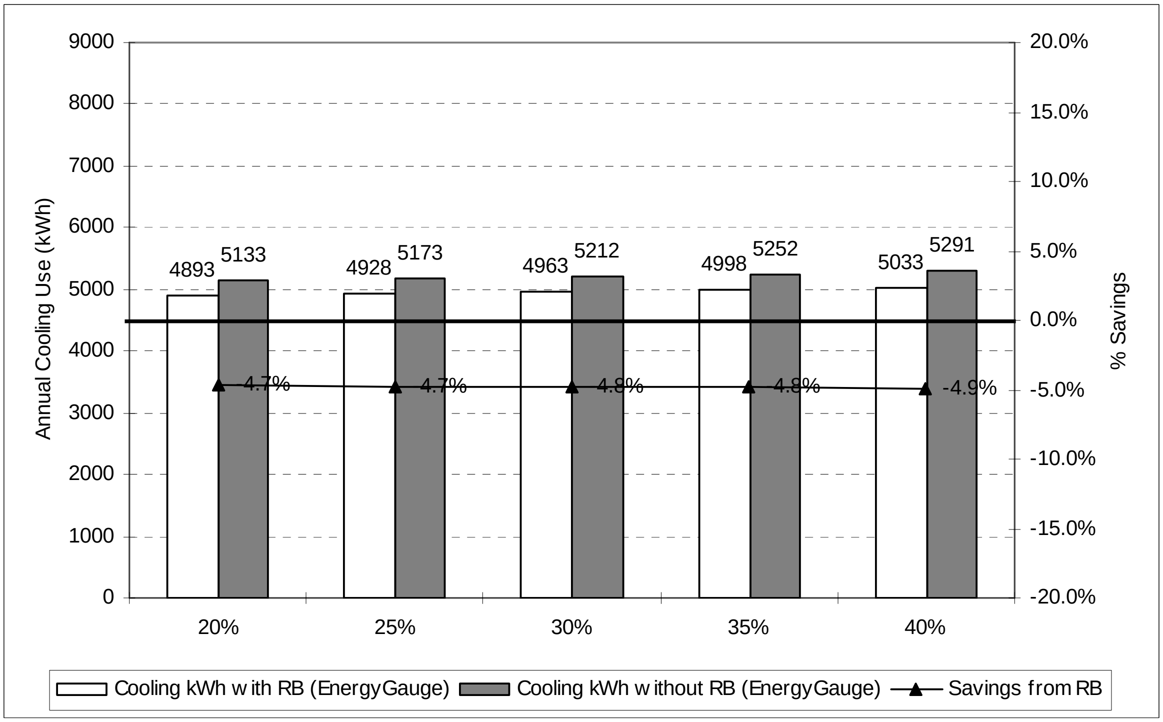

Figure 24. Cooling energy differences and % savings from varying supply duct area (% of conditioned space) with radiant barrier and without radiant barrier – EnergyGauge.

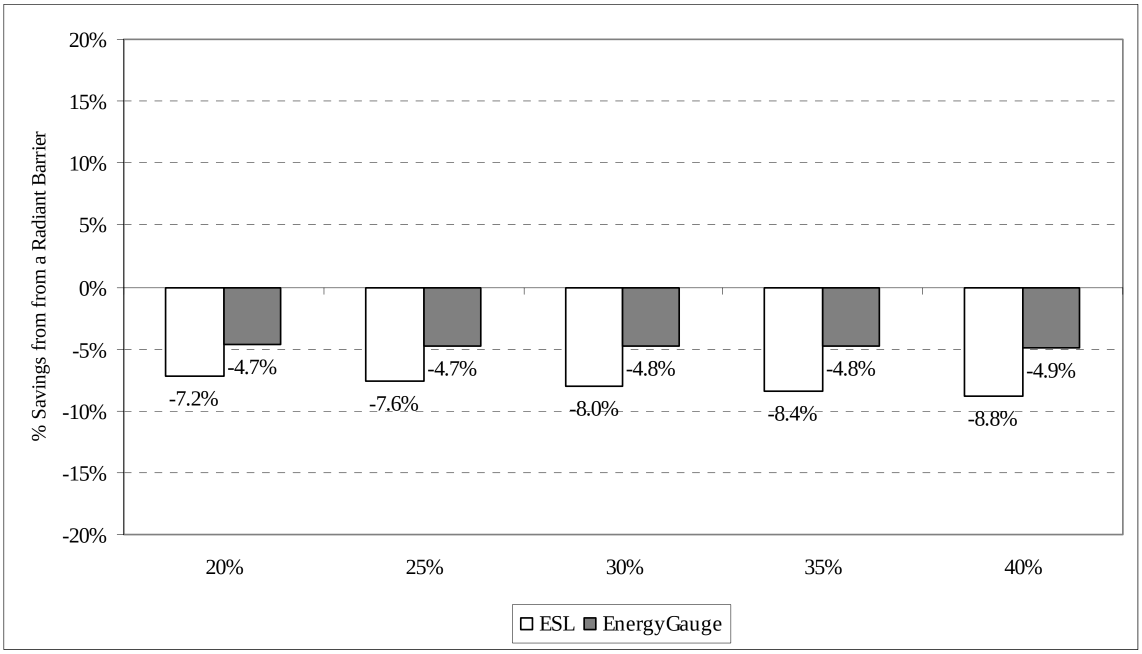

Figure 25. Comparison of cooling savings from varying supply duct area (% of conditioned space) with radiant barrier and without radiant barrier of the ESL model and EnergyGauge.

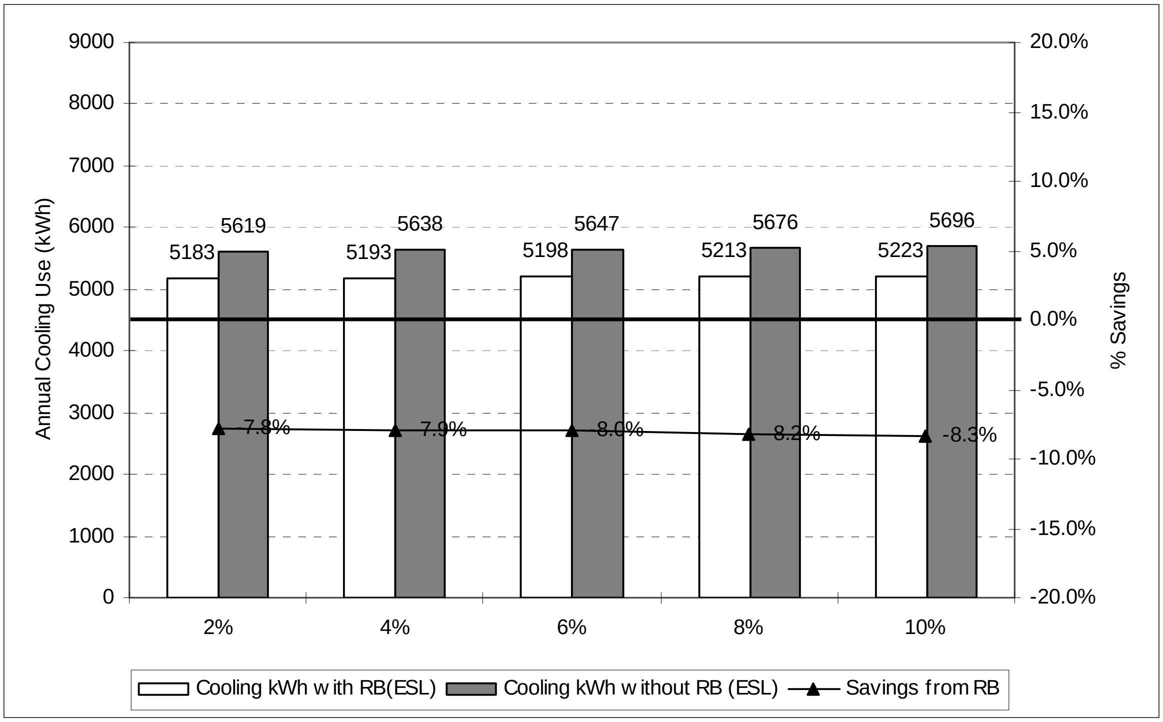

Figure 26. Cooling energy differences and % savings from varying return duct area (% of conditioned space) with radiant barrier and without radiant barrier - ESL model.

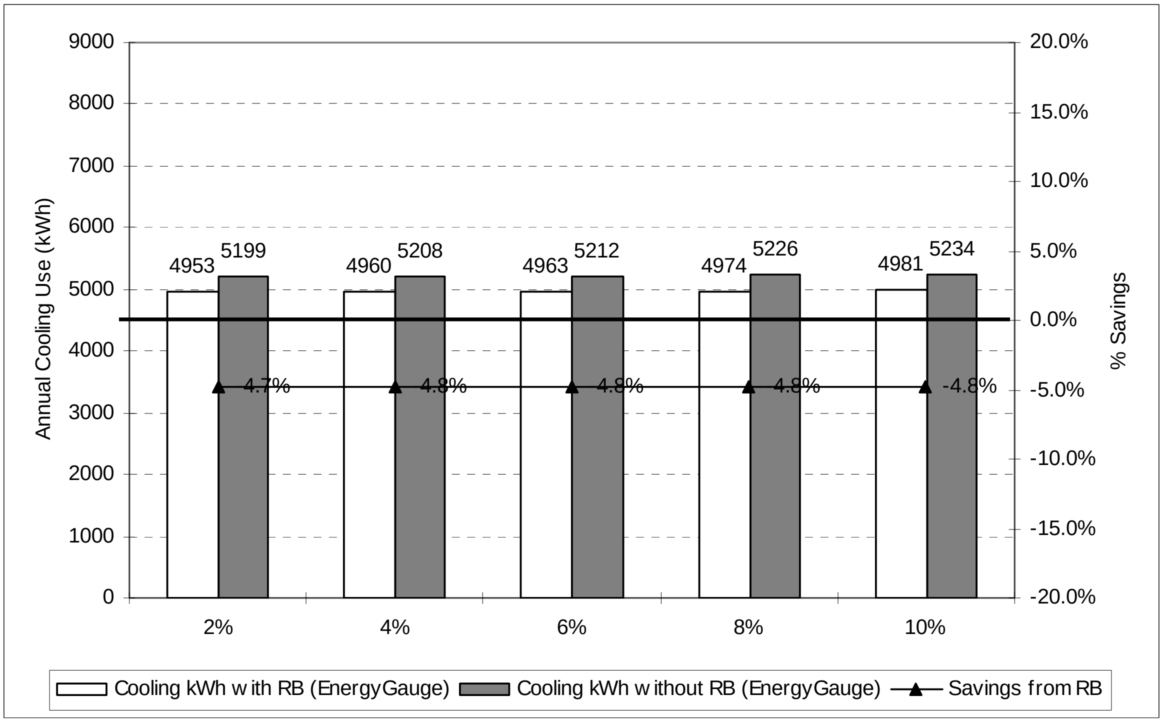

Figure 27. Cooling energy differences and % savings from varying return duct area (% of conditioned space) with radiant barrier and without radiant barrier – EnergyGauge.

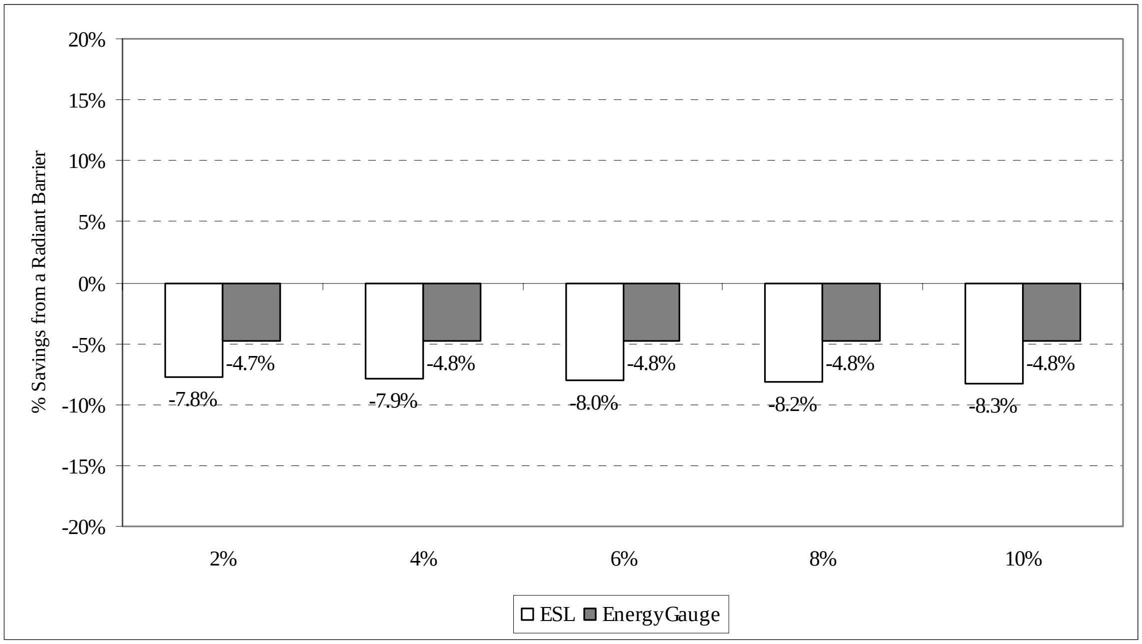

Figure 28. Comparison of cooling savings from varying return duct area (% of conditioned space) with radiant barrier and without radiant barrier of the ESL and FSEC models.

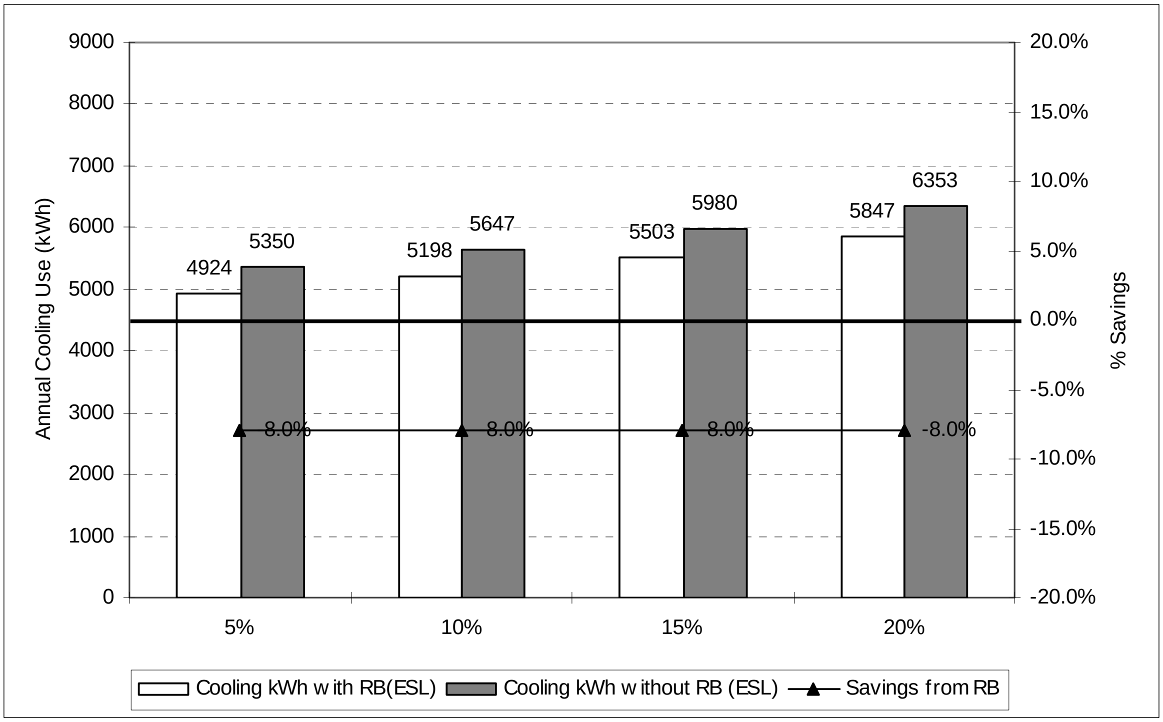

Figure 29. Cooling energy differences and % savings from varying supply duct leakage with radiant barrier and without radiant barrier - ESL model.

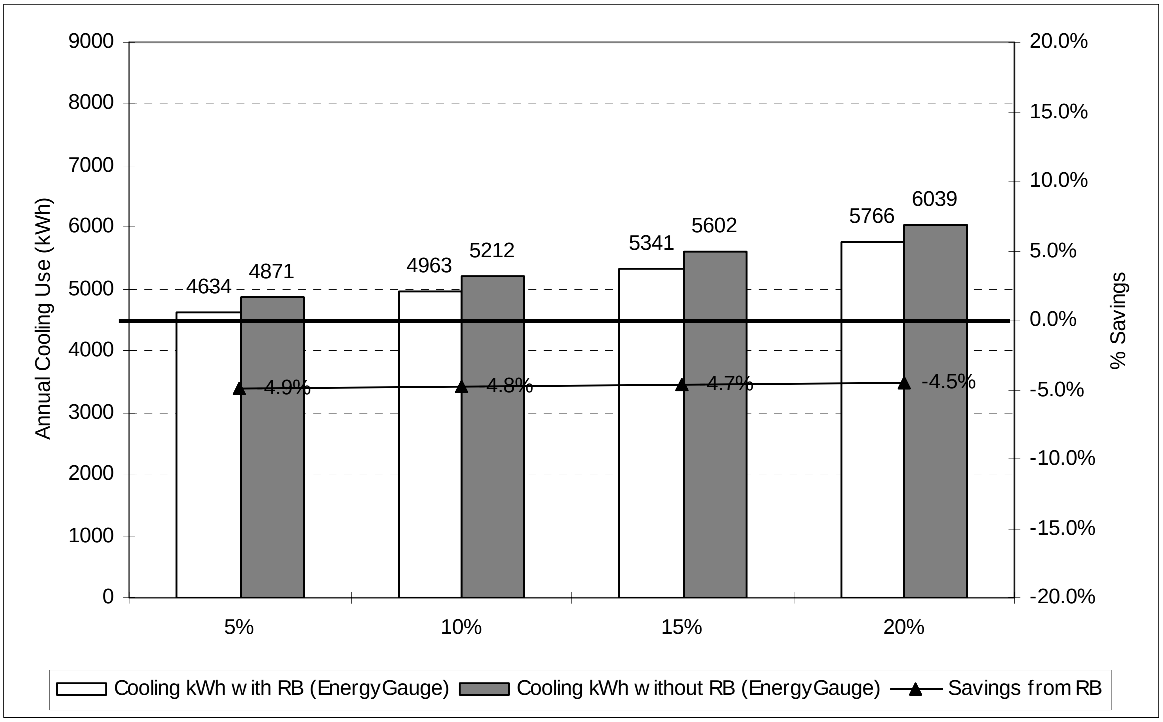

Figure 30. Cooling energy differences and % savings from varying supply duct leakage with radiant barrier and without radiant barrier – EnergyGauge.

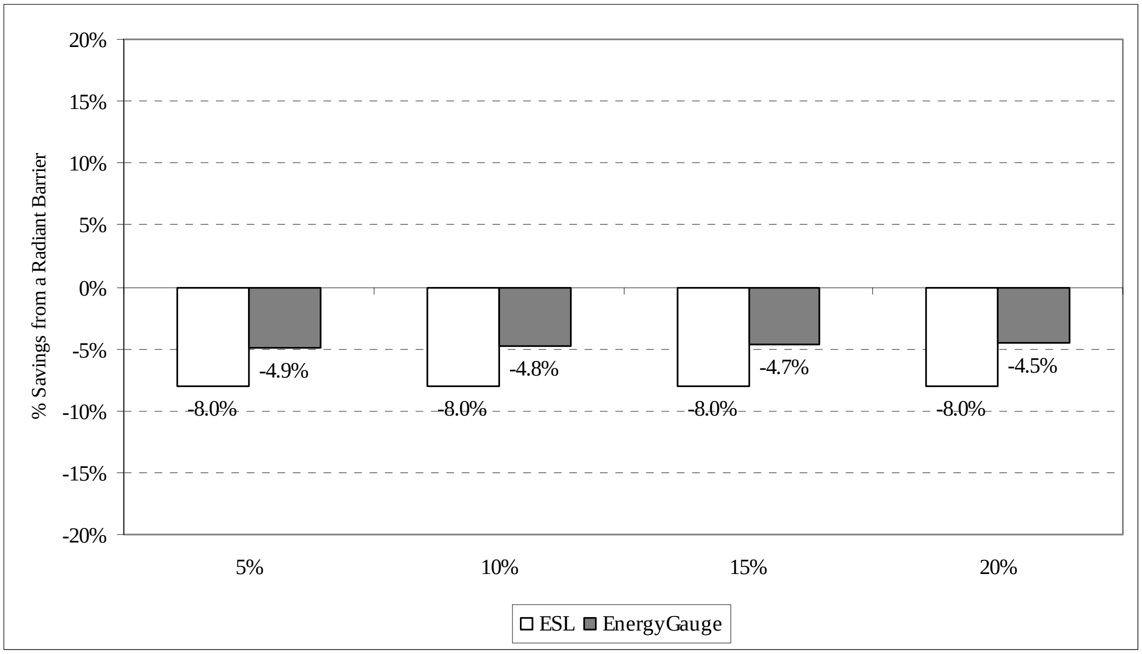

Figure 31. Comparison of cooling savings from varying supply duct leakage with radiant barrier and without radiant barrier of the ESL and FSEC models.

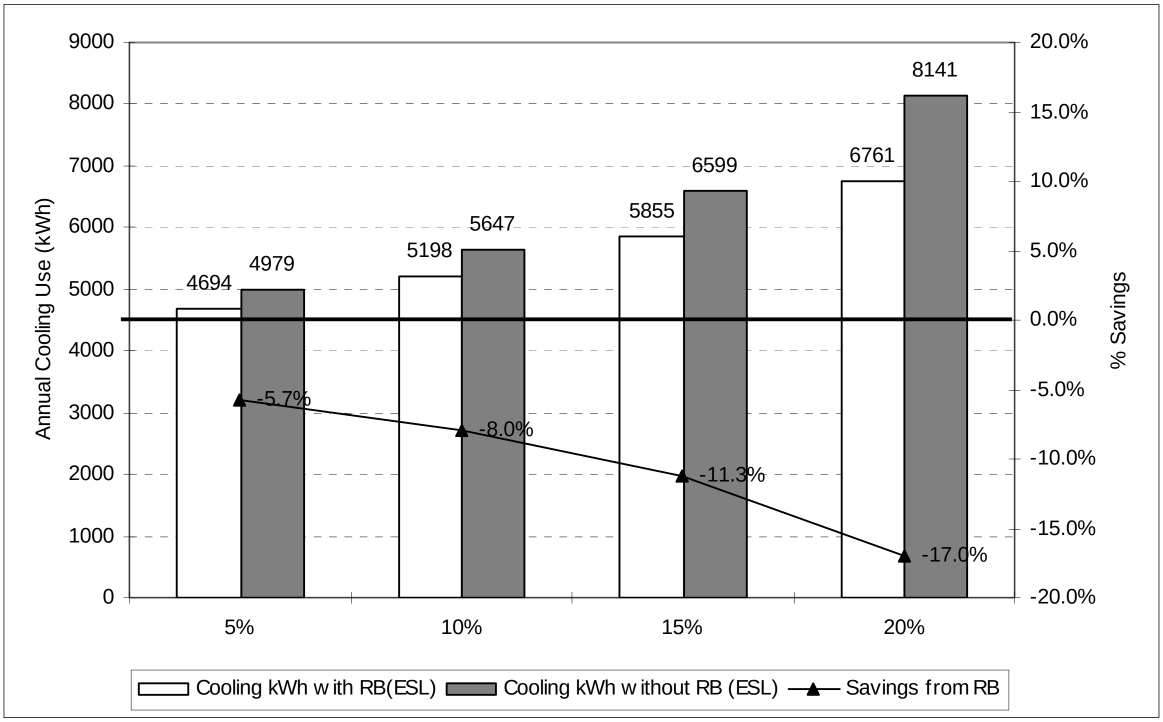

Figure 32. Cooling energy differences and % savings from varying return duct leakage with radiant barrier and without radiant barrier - ESL model.

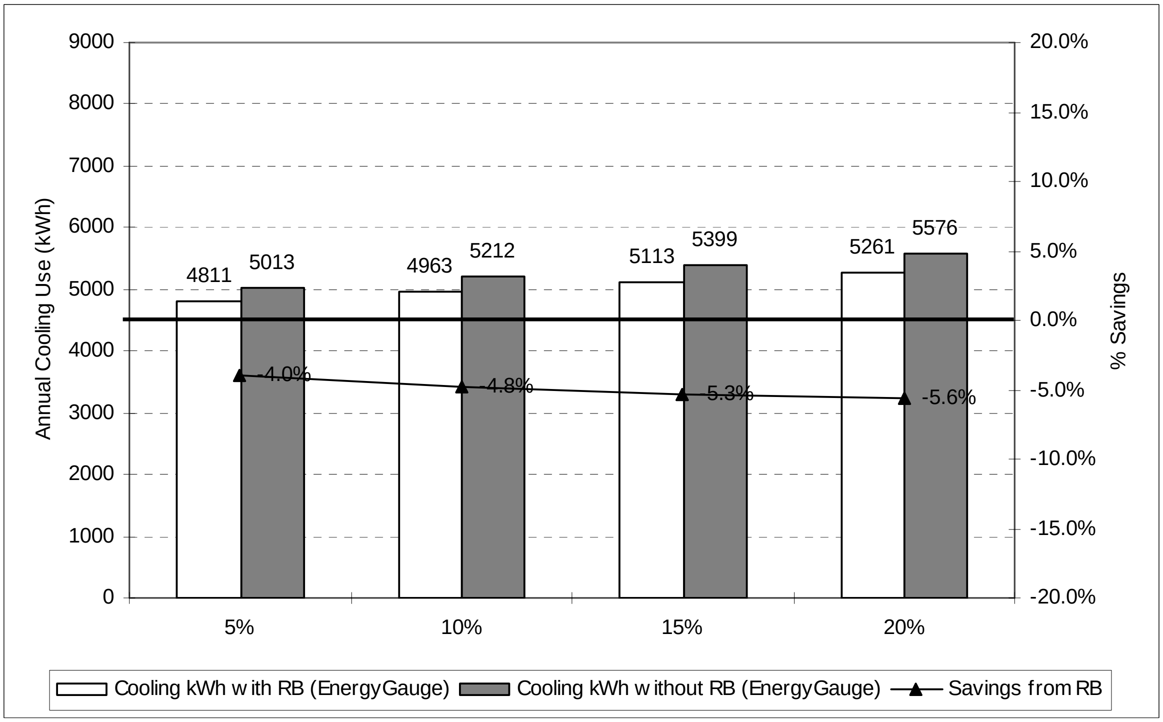

Figure 33. Cooling energy differences and % savings from varying return duct leakage with radiant barrier and without radiant barrier – EnergyGauge.

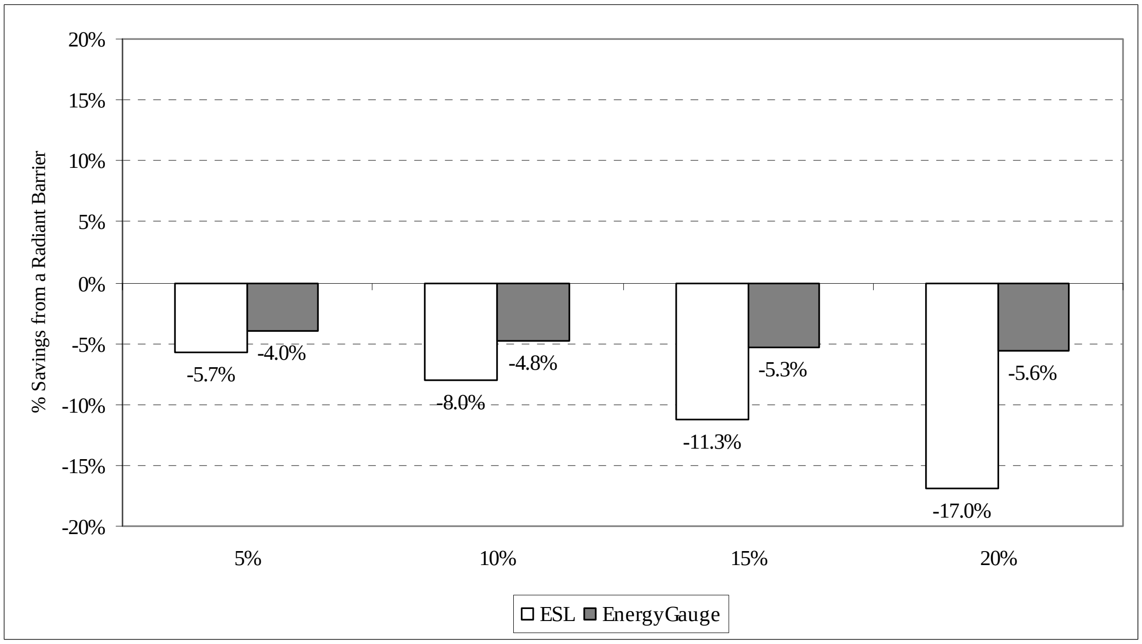

Figure 34. Comparison of cooling savings from varying return duct leakage with radiant barrier and without radiant barrier of the ESL and FSEC models.

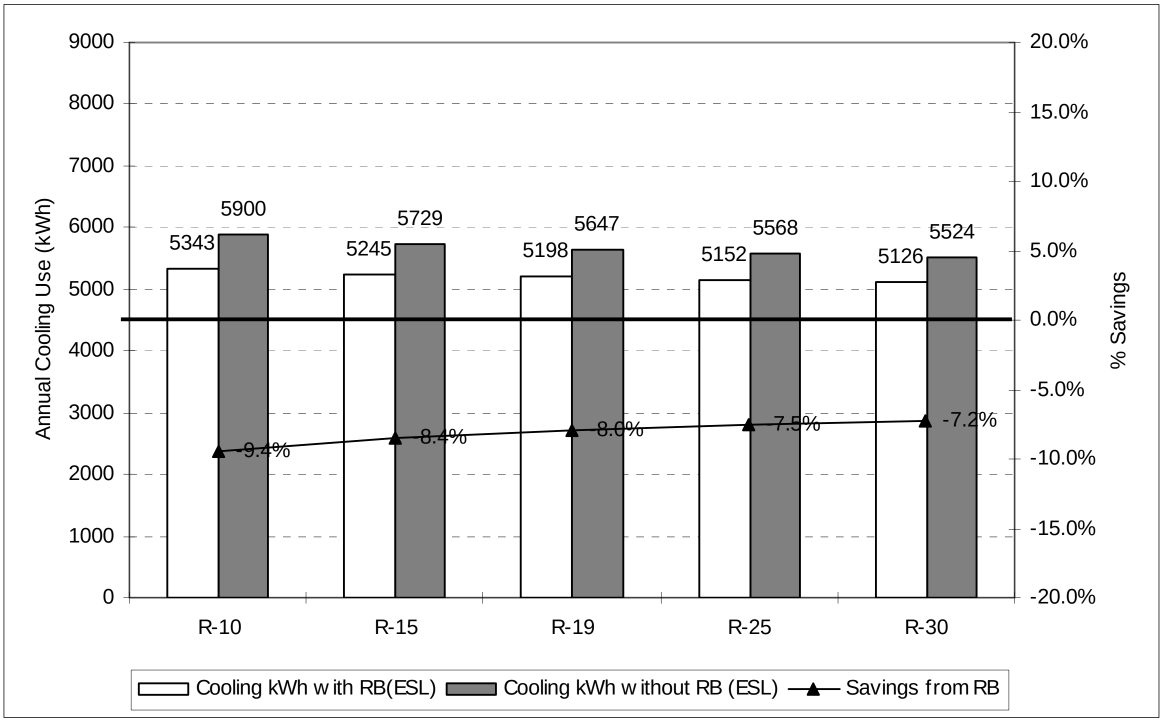

Figure 35. Cooling energy differences and % savings from varying ceiling insulation with radiant barrier and without radiant barrier - ESL model.

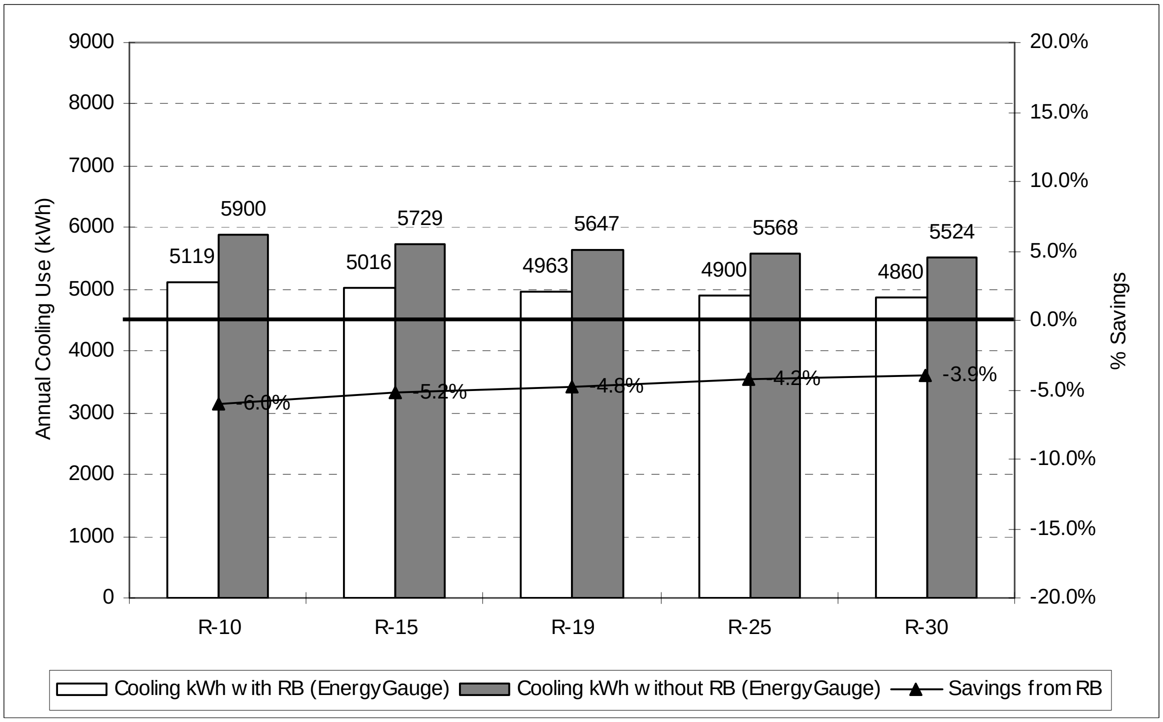

Figure 36. Cooling energy differences and % savings from varying ceiling insulation with radiant barrier and without radiant barrier – EnergyGauge.

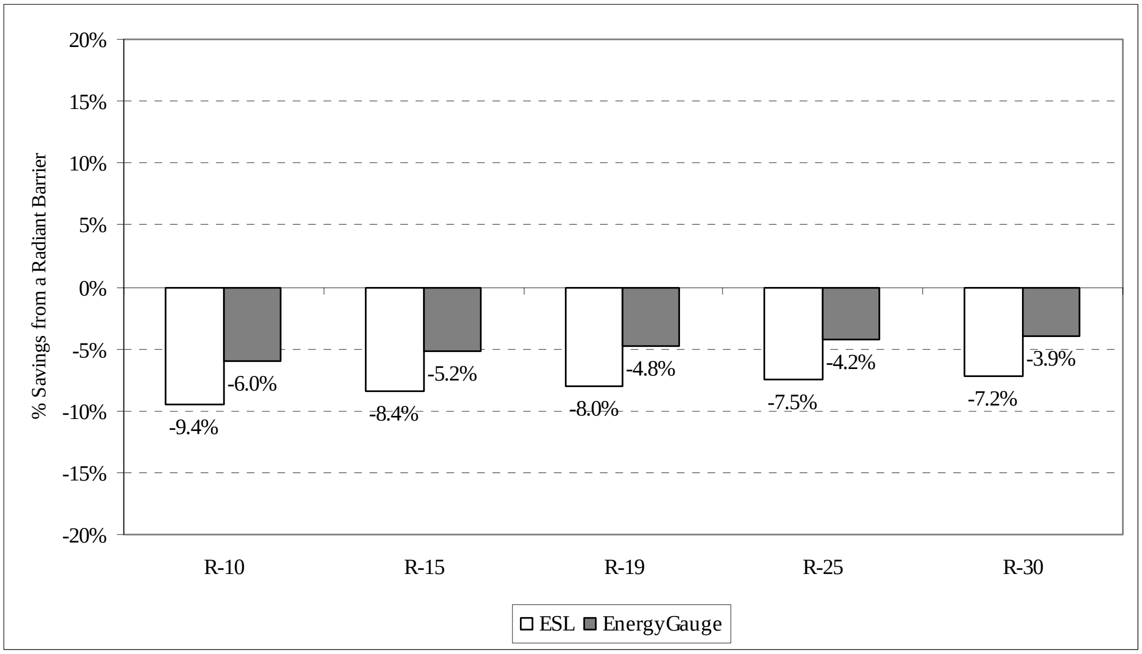

Figure 37. Comparison of cooling savings from varying ceiling insulation with radiant barrier and without radiant barrier of the ESL and FSEC models.

5. Summary

5.1. Comparison of the Results of the Duct Model with Radiant Barrier

Comparison of the results of the duct model with radiant barrier shows acceptable agreements for the parameters of duct insulation, supply duct surface area, return duct surface area, supply duct leakage and ceiling insulation. However, in the case of various return duct leakage, the ESL model shows more sensitivity to leakage than EnergyGauge.

Table 2. Comparisons of the results of the duct model with radiant barrier.

	ESL model	EnergyGauge	Comments (within +/- 5%)
Duct Insulation (R-4 → R-12)	+3% → -3.6%	+1.8% → -2.1%	Acceptable agreement
Supply duct area (% of conditioned space) (20% → 40%)	-2.3% → 2.3%	-1.4% → 1.4%	Acceptable agreement
Return duct area (% of conditioned space) (2% → 10%)	-0.3% → 0.5%	-0.2% → 0.4%	Acceptable agreement
Supply duct leakage (% of conditioned space) (5% → 20%)	-5.3% → 12.5%	-6.6% → 16.2%	Acceptable agreement
Return duct leakage (% of conditioned space) (5% → 20%)	-9.7% → 30.1%	-3.1% → 6.0%	ESL's model shows more sensitivity than EnergyGauge
Ceiling insulation (R-10 → R-30)	2.8% → -1.4%	3.1% → -2.1%	Acceptable agreement

5.2. Comparison of the Results of the Duct Model without Radiant Barrier

Comparison of the results of the duct model without radiant barrier also shows acceptable agreements for the parameters of duct insulation, supply duct surface area, return duct surface area, supply duct leakage and ceiling insulation. However, in the case of various return duct leakage, the ESL model shows more sensitivity to leakage than EnergyGauge.

Table 3. Comparisons of the results of the duct model without radiant barrier.

	ESL model	EnergyGauge	Comments (within +/- 5%)
Duct Insulation (R-4 → R-12)	+5.5% → -4.9%	+2.0% → -2.3%	Acceptable agreement
Supply duct area (% of conditioned space) (20% → 40%)	-3.1% → 3.3%	-1.5% → 1.5%	Acceptable agreement
Return duct area (% of conditioned space) (2% → 10%)	-0.5% → 0.9%	-0.2% → 0.4%	Acceptable agreement
Supply duct leakage (% of conditioned space) (5% → 20%)	-5.3% → 12.5%	-6.5% → 15.9%	Acceptable agreement
Return duct leakage (% of conditioned space) (5% → 20%)	-11.8% → 44.2%	-3.8% → 7.0%	ESL's model shows more sensitivity than EnergyGauge
Ceiling insulation (R-10 → R-30)	4.5% → -2.2%	4.5% → -2.9%	Acceptable agreement

5.3. Comparison of the Results of Saving Difference of the ESL Model and EnergyGauge

The results of savings from simulations with and without radiant barriers indicate that ESL's model shows more savings for all parameters. In terms of sensitivity of the results, the ESL model shows more sensitivity for all parameters except for supply duct leakage. For the supply duct leakage, both models show small changes. The ESL model shows more energy savings.

Table 4. Comparison of the results of savings differences between the ESL model and EnergyGauge.

	ESL's model	EnergyGauge	Comments
Duct Insulation (R-4 → R-12)	-9.4% → -6.7%	-4.9% → -4.6%	ESL's model shows more sensitivity and more energy savings
Supply duct area (% of conditioned space) (20% → 40%)	-7.2% → -8.8%	-4.7% → -4.9%	ESL's model shows more sensitivity and more energy savings
Return duct area (% of conditioned space) (2% → 10%)	-7.8% → -8.3%	-4.7% → -4.8%	ESL's model shows more sensitivity and more energy savings
Supply duct leakage (% of conditioned space) (5% → 20%)	-8.0% → -8.0%	-4.9% → -4.5%	Both models don't show sensitivity. ESL model shows more energy savings
Return duct leakage (% of conditioned space) (5% → 20%)	-5.7% → -17.0%	-4.0% → -5.6%	Both models show sensitivity. ESL model shows more energy savings
Ceiling insulation (R-10 → R-30)	-9.4% → -7.2%	-6.0% → -3.9%	Both models show sensitivity. ESL model shows more energy savings

5.4. Known differences between the ESL Model and EnergyGauge

A review of the results with FSEC on May 11, 2007, revealed the following differences between the ESL model and EnergyGauge:

1. The FSEC model assumes that the ducts are an R-input +1 to account for the fact that ducts often sit on top of the attic insulation, and therefore not all the duct is exposed to the attic condition.

2. For the ceiling insulation, the FSEC model makes an adjustment for heat transfer across the low-density insulation to account for changing insulation conductivity with the mean temperature differences across the insulation.

3. The FSEC model has a full air conditioner model (versus an adjustment to the A/C efficiency) to consider the impact of the duct loss on DOE-2 simulation, which includes changes to the air delivery temperature.

4. The FSEC model uses a different formula for calculating the penalty from return duct losses that reduces the impact of the losses based on empirical results from in-situ field tests.

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Appendix

Tables A.1 to A.3 show the simulation results of various conditions.

Table A. 1. Comparison of Duct Models with Radiant Barrier.

		Cooling kWh (ESL)	Cooling kWh (FSEC)	Saving_Cooling (ESL)	Saving_Cooling (FSEC)
Duct insulation	R-4	5395	5054	3.8%	1.8%
	R-6 (Base case)	5198	4963		
	R-8	5103	4913	-1.8%	-1.0%
	R-10	5048	4881	-2.9%	-1.7%
	R-12	5012	4858	-3.6%	-2.1%
Supply duct area (% of conditioned space)	20%	5080	4893	-2.3%	-1.4%
	25%	5139	4928	-1.1%	-0.7%
	30% (Base case)	5198	4963		
	35%	5258	4998	1.2%	0.7%
	40%	5319	5033	2.3%	1.4%
Return duct area (% of conditioned space)	2%	5183	4953	-0.3%	-0.2%
	4%	5193	4960	-0.1%	-0.1%
	6% (Base case)	5198	4963		
	8%	5213	4974	0.3%	0.2%
	10%	5223	4981	0.5%	0.4%
Supply Duct Leakage	5%	4924	4634	-5.3%	-6.6%
	10% (Base case)	5198	4963		
	15%	5503	5341	5.9%	7.6%
	20%	5847	5766	12.5%	16.2%
Return Duct Leakage	5%	4694	4811	-9.7%	-3.1%
	10% (Base case)	5198	4963		
	15%	5855	5113	12.6%	3.0%
	20%	6761	5261	30.1%	6.0%
Ceiling insulation	R-10	5343	5119	2.8%	3.1%
	R-15	5245	5016	0.9%	1.1%
	R-19 (Base case)	5198	4963		
	R-25	5152	4900	-0.9%	-1.3%
	R-30	5126	4860	-1.4%	-2.1%

Table A. 2. Comparison of Duct Models without Radiant Barrier.

		Cooling kWh (ESL)	Cooling kWh (FSEC)	Saving_Cooling (ESL)	Saving_Cooling (FSEC)
Duct insulation	R-4	5957	5315	5.5%	2.0%
	R-6 (Base case)	5647	5212		
	R-8	5505	5154	-2.5%	-1.1%
	R-10	5423	5117	-4.0%	-1.8%
	R-12	5370	5091	-4.9%	-2.3%
Supply duct area (% of conditioned space)	20%	5474	5133	-3.1%	-1.5%
	25%	5559	5173	-1.6%	-0.7%
	30% (Base case)	5647	5212	0.0%	0.0%
	35%	5738	5252	1.6%	0.8%
	40%	5832	5291	3.3%	1.5%
Return duct area (% of conditioned space)	2%	5619	5199	-0.5%	-0.2%
	4%	5638	5208	-0.2%	-0.1%
	6% (Base case)	5647	5212		
	8%	5676	5226	0.5%	0.3%
	10%	5696	5234	0.9%	0.4%
Supply Duct Leakage	5%	5350	4871	-5.3%	-6.5%
	10% (Base case)	5647	5212		
	15%	5980	5602	5.9%	7.5%
	20%	6353	6039	12.5%	15.9%
Return Duct Leakage	5%	4979	5013	-11.8%	-3.8%
	10% (Base case)	5647	5212		
	15%	6599	5399	16.9%	3.6%
	20%	8141	5576	44.2%	7.0%
Ceiling insulation	R-10	5900	5445	4.5%	4.5%
	R-15	5729	5290	1.5%	1.5%
	R-19 (Base case)	5647	5212	0.0%	0.0%
	R-25	5568	5117	-1.4%	-1.8%
	R-30	5524	5059	-2.2%	-2.9%

Table A. 3. Savings Differences with and without Radiant Barriers for the ESL Model and EnergyGauge.

		ESL			FSEC		
		Cooling kWh with RB	Cooling kWh without RB	Savings from RB	Cooling kWh with RB	Cooling kWh without RB	Savings from RB
Duct insulation	R-4	5395	5957	-9.4%	5054	5315	-4.9%
	R-6	5198	5647	-8.0%	4963	5212	-4.8%
	R-8	5103	5505	-7.3%	4913	5154	-4.7%
	R-10	5048	5423	-6.9%	4881	5117	-4.6%
	R-12	5012	5370	-6.7%	4858	5091	-4.6%
Supply duct area (% of conditioned space)	20%	5080	5474	-7.2%	4893	5133	-4.7%
	25%	5139	5559	-7.6%	4928	5173	-4.7%
	30%	5198	5647	-8.0%	4963	5212	-4.8%
	35%	5258	5738	-8.4%	4998	5252	-4.8%
	40%	5319	5832	-8.8%	5033	5291	-4.9%
Return duct area (% of conditioned space)	2%	5183	5619	-7.8%	4953	5199	-4.7%
	4%	5193	5638	-7.9%	4960	5208	-4.8%
	6%	5198	5647	-8.0%	4963	5212	-4.8%
	8%	5213	5676	-8.2%	4974	5226	-4.8%
	10%	5223	5696	-8.3%	4981	5234	-4.8%
Supply Duct Leakage	5%	4924	5350	-8.0%	4634	4871	-4.9%
	10%	5198	5647	-8.0%	4963	5212	-4.8%
	15%	5503	5980	-8.0%	5341	5602	-4.7%
	20%	5847	6353	-8.0%	5766	6039	-4.5%
Return Duct Leakage	5%	4694	4979	-5.7%	4811	5013	-4.0%
	10%	5198	5647	-8.0%	4963	5212	-4.8%
	15%	5855	6599	-11.3%	5113	5399	-5.3%
	20%	6761	8141	-17.0%	5261	5576	-5.6%
Ceiling insulation	R-10	5343	5900	-9.4%	5119	5445	-6.0%
	R-15	5245	5729	-8.4%	5016	5290	-5.2%
	R-19	5198	5647	-8.0%	4963	5212	-4.8%
	R-25	5152	5568	-7.5%	4900	5117	-4.2%
	R-30	5126	5524	-7.2%	4860	5059	-3.9%